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О К ЛАНГЕ М Ф ИВАНОВА Н Е ЛЕБЕДЕВА

ОБЩАЯ ГЕОЛОГИЯ

CONTENTS

INTRODUCTION

Geology is a science which treats of the Earth But this definition has to be specified because the Earth is studied by many sciences that have their own specific tasks and methods of investigation

Modern geology studies the history of the Earth and its life In conformity with this task, it is divided into two closely related sections which are sometimes regarded as separate disciplines a) *dynamic (physical) geology* which deals with the causes and processes of geological change and b) *historical geology* which studies crustal changes in time and space and the relation between the development of the organic world and the Earth s crust

This book describes the geological processes on the surface of the Earth and in it outlines the history of the Earth s crust and gives a geological chronology

To enable readers to understand geological processes more fully the authors touch upon problems of astronomy and physical geography and discuss the Earth s position in space and also the various hypotheses on the Earth s origin The purpose of this book is to teach people to recognise ore-forming and other widespread minerals as well as rocks use a geological compass read geological maps and construct geological sections

Ferrous and non ferrous metallurgy the fuel and chemical industries agriculture and other branches of the national economy owe their existence and development to minerals and geology provides the knowledge needed to look for and exploit these minerals By studying the structure, composition and history of the Earth s crust geologists uncover

the wealth hidden in the bosom of the Earth and develop efficient methods of tapping this wealth. Moreover, the information yielded by geology is of the utmost importance to building. The builders of big factories and civil buildings, railways, oil and gas pipelines, tunnels, bridges, dams and reservoirs require preliminary geological information on the bedding of rocks in and around building sites, the composition of these rocks and the conditions under which they formed, the processes changing these rocks, and the future direction of these changes.

Man has always evinced an interest in geology. This is borne out by the fact that he learned to produce metals long before the dawn of our era. But it was only in the first half of the nineteenth century that the first chronology of the Earth's history was compiled and theories were advanced *on the formation of mountains*.

The extensive factual material yielded by investigations in vast areas in Europe, Asia and America provided the foundation for scientific generalisations.

Many Russian, West European and American scientists have helped to formulate the fundamentals of geology. Of the Russian geologists special mention must be made of Mikhail Lomonosov (1711-1765), who came forward with important ideas about the Earth's origin and geological structure and did much to further mining. Outstanding work was done at the close of the eighteenth and beginning of the nineteenth century by Vasily Severgin (mineralogy), Nikolai Koksharov (crystallography) and Dmitry Sokolov (geology). The Russian scientists who made important contributions to geology in the second half of the nineteenth and early twentieth century include Gennady Romanovsky, Alexander Karpinsky, Vladimir Obruchev, Ivan Gubkin, Andrei Arkhangelsky (geology), Vladimir Kovalevsky, Nikolai Yakovlev, Alexei Borisyak, Alexei Pavlov, M. V. Pavlov (paleontology), Yevgraf Fyodorov (crystallography), Vladimir Vernadsky, Alexander Fersman and Frants Levinson-Lessing (petrography and geochemistry).

Abroad, the outstanding investigators in the nineteenth and twentieth centuries include William Smith (Great Britain) and Georges Cuvier (France), who proved that fossil organisms play an important role in the consecutive strati-

graphy of sediments, Charles Lyell (Great Britain) who introduced the actualistic method (whereby the past is studied through the present) into geology, Eduard Suess (Austria) who studied the structure of the Earth s crust, E Haug (France) who developed the geosynclinal theory Albert Heim (Switzerland) Leopold Kober (Austria) and James Dwight Dana (U S A) who studied tectonics and Alfred Lothar Wegener (Germany) who developed the theory that continents float on a bed of molten magma

Soviet scientists have done much to develop the theory of geology and to enlarge the raw material resources of the Soviet mining industry This work is being facilitated by the Soviet Union s far reaching plans of economic development The Soviet Union s enormous territory and the great diversity of her geological structure likewise provide considerable opportunity for geological study and generalisations

In the past few decades Soviet geologists have discovered new reserves of ferrous non ferrous and rare metals, oil and other minerals Soviet industry now has all the mineral raw materials it requires

Huge aluminium deposits have been discovered on the eastern slopes of the Ural Mountains in the Tikhvin area in the Ukraine and other regions of the U S S R Many years ago Academician Andrei Arkhangelsky had insisted there were aluminium ores (bauxites) in these regions

The discovery of huge iron ore deposits became possible thanks to our greater knowledge of the genesis of iron ores which as we now know, form not only where sedimentary and magmatic rocks come into contact but also far from these points of contact, in coastal regions, as well as in the weathering crust of rocks

Academician Ivan Gubkin whose forecasts helped to discover oil and natural gas deposits played an important role in developing the theory of the formation of these deposits

Theoretical premises have in a large measure been responsible for the discovery of diamond fields in Yakutia

Geological investigations have strengthened and enriched hydrogeology, engineering geology geotectonics, geocryology, volcanology, paleontology and other disciplines, and

have also given rise to many new geological disciplines Geochemistry and geophysics emerged during the present century and are developing rapidly Geochemistry which owes its rise mainly to the investigations of the Soviet scientists Vladimir Vernadsky and Alexander Fersman studies the history of the chemical elements in the Earth s crust the laws governing their distribution and also their behaviour under various physical and chemical conditions Geophysics studies the physical properties of the Earth as a whole and its separate regions through various instrumental observations Geophysical methods are very important in the search for mineral deposits

In studying the Earth s crust its formation and its changes in time geology draws upon the basic theories of physics chemistry and biology But the methods of investigation used in geology differ greatly from chemical and biological methods In physics chemistry and biology various laws are established through experimentation but it is extremely difficult to conduct experiments in geology It is hard for example to create the necessary conditions for orogenic processes which gave rise to mountain ranges over a period of many millions of years But experiments modelling various geological processes are being conducted in many countries including the Soviet Union

Geology s principal method of investigation is to conduct close field observations of the consecutive stratification of rocks (strigraphy) their structural features (tectonics) composition (petrography) and relative age on the basis of the fossil fauna and flora preserved in them (paleontology)

Soviet scientists are penetrating ever deeper into the essence of the processes they are studying generalising data by methods of dialectical materialism and formulating hypotheses on the geological processes in remote periods of the Earth s history

The structure of abyssal layers which cannot be reached for direct observation is tudied by the products of volcanic eruptions Investigations of earthquakes and of the pa s age of seismic waves through the Earth give some idea of the tate of matter in the Earth Important conclu ions have been arrived at through a tudy of geothermal phenom

ena Observations in this field have shown that the great reserves of heat in the Earth play a very important role in the processes forming the Earth s crust the secular variations of the boundaries of continents and seas the presence of hot springs and other phenomena

Instrumental geophysical methods of investigation (seismometry magnitometry gravimetry and so on) which allow studying the passage of seismic waves through various mantles of the Earth magnetic phenomena the distribution of the forces of gravity and other phenomena, have enabled scientists to unfathom many secrets of the structure of the Earth s crust

ORIGIN OF THE EARTH, ITS PHYSICAL AND CHEMICAL PROPERTIES

THE EARTH IN COSMIC SPACE

The Earth is one of the planets of the solar system and revolves round the Sun like all the other planets of this system The planets revolving round the Sun are situated in a single plane, namely, in the plane of the ecliptic which forms an angle of about 7° with the solar equator

The problem of the origin of the solar system and of the entire universe is of great theoretical and practical importance

All scientists agree that celestial bodies were formed of identical matter Various hypotheses were enunciated to explain the origin of the solar system One of the first was the hypothesis advanced by Immanuel Kant (1724 1804) in 1755

He said the universe was formed of the primary matter filling cosmic space The particles of this apparently solid matter were in a state of rest but differed from each other in density and mass Attracted by mutual gravitation they began to move and form separate condensations These condensations continued to interact the bigger condensations attracting the smaller ones in the sphere of their action Thus were formed large knots of matter But besides gravitational forces there are forces of mutual repulsion, under the action of which colliding particles bounce away from each other in different directions The direction that the moving particles were given most frequently became predominant and a mass of knots of matter began to revolve in one direction round a bigger knot, round a central body—the Sun

The particles revolving round the Sun represented rings of a meteor shower which had its own centres of attraction—the nuclei of future planets. Gradually uniting under the force of gravitation all meteors are thus transformed into a system of planets circling round the Sun (Fig. 1).

In 1796 Pierre Laplace (1748-1827) advanced a similar hypothesis of the origin of the solar system and other worlds. His hypothesis was that the matter of which the Sun, the

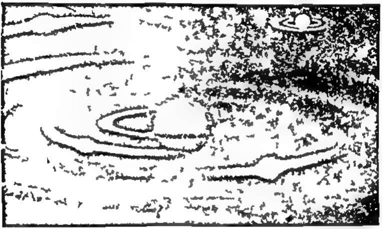

Fig. 1. Formation of the Sun and the planets after Kant-Laplace

planets and their satellites consist was at one time a rarefied gaseous cloud (nebula) which was in a state of rotation (the cause of which is unknown). On account of the attraction between the particles this nebula began to condense in its centre and this led to the formation of the primeval Sun. In the beginning it was enveloped in a nebula revolving evenly round it. The particles nearest to the Sun thus described orbits of lesser radius, while those more distant described orbits of bigger radius in the same span of time. Therefore the farther away from the centre and the weaker the gravitation, the greater the centrifugal force became. At a certain distance from the centre these forces struck a balance. The boundary separating the given system from the others passed through this point.

Giving away its heat into space, the revolving nebula gradually cooled down and consequently, contracted That led to an increase of the velocity of rotation which at length attained a value at which the centrifugal force exceeded the inward pull of gravity On account of this, the nebula began to lose its spherical form and to change into a more and more pronounced spheroid Round its equator the nebula began to disintegrate into several narrow and thin rings Under the influence of uneven cooling the rings broke off and owing to the attraction between the particles the planets revolving round the Sun were formed (Fig 1)

In contrast to Kant s hypothesis which drew no attention Laplace s propositions became very popular as soon as they were published and they influenced the development of astronomy in the nineteenth century Laplace s hypothesis explained why the planets revolved round the Sun in the same direction as the Sun was rotating round its own axis why their orbits were arranged nearly in the same plane why they were rotating round their axes in the same direction as the Sun and so on

At present the hypotheses of Kant and Laplace whose content is very nearly the same are known as the Kant Laplace hypothesis

Further study of the universe and the solar system revealed numerous facts that contradicted the Kant Laplace propositions It became known for example that the satellites of some planets do not rotate in the same direction as the planets themselves (this concerns some of the satellites of Uranus and Jupiter)

Other cosmogonical hypotheses (the hypotheses of Moulton Chamberlin, Jeans and others) developed out of the Kant Laplace hypothesis in the twentieth century

In the past few decades the Soviet scientists who have been developing cosmogonical hypotheses have introduced essential corrections into the scientific ideas advanced in the nineteenth and early twentieth centuries One of them Otto Schmidt believed the early hypotheses were untenable because they were only qualitative Modern cosmogony he said should also engage in quantitative study based on mathematical and statistical methods

In 1944 Schmidt put forward a new hypothesis in which

it was assumed that the planets of the solar system originated from a gas dust nebula attracted by the Sun as it moved in interstellar space

The solid meteorite particles revolving round the Sun united under the influence of gravitation and gave rise to the planets This *process of unification of the planets proceeded* rather intensively so long as the meteor shower was dense but in the last 2 000 million years the addition of meteorites to the Earth has been very inconsiderable The redistribution of the meteorite mass within the Earth proceeded only in a viscous plastic state without transition through a fluid stage The Earth according to Schmidt was never hot its average temperature never exceeding 4° The subsequent heating of the Earth is associated with the decay of radioactive elements

Schmidt s hypothesis plausibly explains all the structural features of the solar system the circular orbits the revolution of the planets the laws governing the spacing of the planets the division of the planets into two groups (large planets and planets of the terrestrial type) moreover on the assumption that planets received their quantity of motion from without during the capture of a gas dust cloud at the expense of the enormous momentum of rotation of the Galaxy it solves the major problem of the distribution of mass and momentum in the solar system

The weak point in Schmidt s hypothesis was however the problem of the origin of the meteorite gas dust cloud round the Sun which was the initial material for the formation of the planets The possibility of the Sun capturing such a cloud from the Galaxy has been mathematically proved for the case of interaction of three bodies yet this possibility is so rare that it makes the process of the formation of planets a unique phenomenon in the universe This compels scientists to seek other explanations of the origin of the gas dust cloud round the Sun

The investigations of the Soviet astrophysicist V A Ambartsumyan are of particular importance in this connection He proved that stars are forming continuously through the condensation of matter in rarefied gas dust nebulae

On the basis of this fact the Soviet astronomer V G Fesenkov developed the hypothesis that the Sun and the plan

ets revolving round it originated from a common gas dust medium According to his hypothesis at the time the Sun was formed as an ordinary star its huge mass and fast rotation caused matter to separate from its equatorial plane This matter formed a gas dust cloud of unequally distributed density The subsequent evolution of this cloud proceeded under the influence of gravity, and led to the creation of the planets The formation of the planets is thus a part of the general process of the formation of stars and appears to be a widespread phenomenon in the universe According to Fesenkov the Earth as all the other planets took shape immediately throughout its mass and not as a result of a long process involving the concentration of separate particles of dust

It is now generally accepted that the Sun and the nine known planets revolving round it represent a planetary system which travels in space at a very high speed The solar system moves at a velocity of 233 kilometres per second

The group of the minor planets of the terrestrial type is nearest to the Sun These planets are relatively small and their density is very high If we take the mean distance from the Earth to the Sun (149 500 000 kilometres) as our unit of distance we shall find this group of planets in the following order in relation to the Sun Mercury 0 39 unit, Venus 0 72 unit, the Earth 1 0 unit and Mars 0 52 unit

They are separated from the outer group of major planets by a belt of asteroids (or planetoids), which consist of accumulations of small planet like bodies revolving about the Sun in elliptical orbits, and oriented in different directions Fesenkov estimates the total mass of asteroids as 0 0003 of the Earth s mass

The major planets whose mass comprises 99 5 per cent of all planetary matter are arranged in relation to the Sun in the following order Jupiter 5 20 units Saturn 9 55 units Uranus 19 19 units, Neptune 30 07 units and Pluto 39 65 units

If we adopt the diameter of the Earth as one unit of measurement, the diameter of Mercury will only be 0 38 unit, of Venus 0 97 unit and of Mars 0 5 unit The diameters of the major planets will then be Jupiter 11 units, Saturn 9 5 units Uranus 4 units and Neptune 3 89 units (Fig 2) as re

gards Pluto's diameter it is believed to be anything from half to about the same as the Earth's

Astronomers have established that the density of the terrestrial planets is greater than that of the major planets. The density of the Earth in G/cm^3 is equal to 5.52, the density of Jupiter 1.3, while the density of Saturn is only 0.7, i.e. less than the density of water

Six planets have satellites. Most of the satellites revolve round the planets in the same direction as their parent bodies revolve round the Sun. Jupiter has the largest number of satellites—12. Eight of them revolve round Jupiter in the same direction as the planet itself, while the remaining four revolve in the opposite direction

Mars has two satellites, Saturn nine and also a ring, Uranus five, and Neptune two. The Moon is the Earth's satellite. Mercury, Venus and Pluto have no satellites

There are thus nine planets and forty satellites (not counting Saturn's ring) in the solar system. On January 2, 1959 the U.S.S.R. launched a space rocket which broke loose from the Earth's gravitation and went into orbit round the Sun, thereby becoming the first man-made satellite of the solar system

Comets are also a part of the solar system. Observed from the Earth, they appear as luminous nebular spots (head of the comet) from which a luminous tail streams out. Comets consist of extremely rarefied gases (chiefly carbon monoxide and cyanogen) and of tiny particles of cosmic dust which reflect the sunlight. A certain consolidation is observed only at the head or nucleus of a comet. This nucleus evidently consists of an accumulation of stones and boulders spaced at small intervals. The mass of a comet is infinitesimal and does not exceed the mass of small asteroids (calculated in million millionth parts of the Earth's mass)

Like the planets, comets revolve round the Sun in elliptical orbits. Only some of them move along slightly elongated ellipses and can therefore be periodically observed from the Earth. The orbits of the majority are so strongly elongated that it takes them hundreds and sometimes thousands of years to complete one revolution round the Sun

Planets with a high density, as well as asteroids, have the same mineral composition as the Earth. This is proved by the

meteorites that have fallen on the Earth These meteorites are fragments of disintegrated cosmic bodies whose composition was similar to that of terrestrial type planets The mineral composition of the meteorites has been studied quite comprehensively None of the minerals in them are unknown to us Some of the meteorites have a high specific weight and consist of iron and nickel, others consist of lighter minerals and are known as stony meteorites

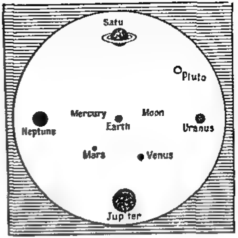

Fig 2 Relative size of the Sun the planets and the Moon

Many of the smaller fragments of cosmic bodies that get into the Earth s atmosphere burn up completely before they reach the Earth's surface and a part of them sweep past the Earth

Being one of the planets of the solar system the Earth is influenced by the Sun and the other planets of this system But the greatest influence on the life of the Earth is exerted by the Sun and the Moon The Moon is 384 395 kilometres or 60 terrestrial radii away from the Earth

A number of geodynamic processes, called exogenous (external) processes, are determined first by the revolution of the Earth round the Sun and second by the fact that the Earth receives heat from the Sun The latter factor strongly influences the conditions and mobility of the Earth s atmosphere The phenomenon of ocean tides is produced by the combined gravitational attraction of the Sun and Moon upon the Earth *The age of the Earth as a planet is enormous* —about 4 000 million years

THE EARTH'S SHAPE, PHYSICAL PROPERTIES AND COMPOSITION

Shape of the Earth Until the seventeenth century it was believed that the Earth was a regular sphere. However by the close of that century many facts had been accumulated which indicated that the Earth was not a sphere. The oscillations of the second pendulum were observed in France and in the equatorial part of America, and these studies showed that the oscillations were slower in the south than in the north. Hence it was inferred that the Earth bulged more in the equatorial region than in the polar region.

Independently of these observations, some scientists came to the conclusion that the Earth was a spheroid with the polar axis somewhat shorter than the equatorial axis.

This conclusion arose from the theoretical reasoning that at one time the Earth was in a fluid or plastic state. Owing to its rotation about its own axis through the action of centrifugal forces, the Earth unavoidably became flatter at the poles and expanded at the equator.

In the seventeenth-nineteenth centuries, to solve the problem of the Earth's shape, the length of the meridian arc was measured at different latitudes by the triangulation method. These measurements showed that the length of the meridian arc corresponding to one degree of latitude increased from the equator towards the pole. In particular, Russian scientists took a number of latitudinal measurements, which to this day constitute the greater part of the geodetic work that has been done to measure the 52nd parallel. The line of measurement begins in England, passes through Belgium, Germany and Poland, and stretches in Russia up to the town of Orsk in the Trans-Ural region. Thus nearly two-thirds of this line is in Russia.

Different lengths of the equatorial and polar semi-axes or the Earth's radii have been established as a result of numerous longitudinal and latitudinal measurements of the Earth's surface. According to these measurements, the equatorial radius is 21 kilometres longer than the polar radius. It is now accepted that the radius of the Earth averages 6 378 kilometres, the Earth's contraction is 1/298, and its surface has an area of 510 100 934 square kilometres.

The exact determination of the shape of the Earth is of importance to theory and practice. The reason for this is that it affects the accuracy of geodetic surveying and cartography. The radii given above show that the globe is flattened at the poles and that its shape is close to that of an oblate spheroid. Detailed geodetic and geophysical investigations have also established that the equatorial radii are not equal in length either. On the equator there is a difference of 213 metres in the length of the radii. The Earth is thus considered to be a triaxial ellipsoid which has been named the Krasovsky ellipsoid; this shape is also known as a *geoid*, i.e., a shape that is distinctive of the Earth only and cannot be reflected by any proper geometric form. The Earth's surface has an amplitude of unevenness of 20 kilometres.

Force of Gravity. The unique shape and structure of the Earth cause changes in the pull of gravity on its surface. Recent accurate measurements of the force of gravity give an idea of the laws governing its distribution on the Earth's surface. There is greater gravity in the polar than in the equatorial region and gravitational acceleration changes smoothly from the pole towards the equator by half a per cent. However, a deviation from this rule is observed at a number of points: in some places the force of gravity is above normal (positive gravity anomaly) and in others it is below normal (negative gravity anomaly). Anomalies are brought about by rare changes in the composition of rocks. Gravity decreases in places consisting of light rocks and increases where the rocks are heavy.

Gravity is measured with special instruments called gravity meters, and the study of the changes in the force of gravity is the subject of the science of gravimetry. In recent years this science has begun to play an important role in helping to solve major problems of geology. Gravimetric maps that reveal a rather close relationship between the force of gravity and geological structure are compiled on the basis of measurements of the force of gravity.

Density of the Earth. It has been established that despite the great difference in the density of individual component rocks, the density of the Earth's crust varies from 1.5 to 3.4, averaging 2.7. This is the density of the most widespread rocks, such as sandstone, clay, chalk, limestone, granite,

basalt, and so on The density of the Earth as a whole, determined by dividing its volume by its weight is 5 52

The geophysicist Philipp von Jolly was first to establish the density of the Earth He obtained the value of 5 692 with a possible error of ± 0 068 The Earth's density has subsequently been determined at different points (in mountains mines and valleys) by many investigators with ordinary and torsion balances pendulums, plumbs and other instruments only slight deviations from the above average density have been recorded

Since the density of the Earth averages 5 52 and the density of the Earth s crust varies from 1 5 to 3 3 it is supposed that in the centre of the Earth there are very heavy masses with a density of not less than 12 which is roughly equal to the density of lead

The approximate density of matter in the interior of the Earth at different depths has been established through a study of the diffusion velocity of seismic oscillations At the same time it has also been ascertained that the diffusion velocity of seismic oscillations which as a rule increases smoothly with depth undergoes sharp changes at certain depths

The direction of seismic rays also changes sharply at these depths where the rays refract and are even partially reflected These sharp changes are observed at depths of from 5 to 70 kilometres On continents they are observed at a greater depth and in oceans—nearer to the Earth s surface These are known as surfaces of the first order The first has been named after Mohorovic the Czech scientist who discovered it At 2 900 metres longitudinal waves refract with particular sharpness while transverse waves fade This is an indication that the physical properties of rock have undergone sharp changes at 2 900 metres

The rate of diffusion of longitudinal waves in the first depth division is 5 5 6 5 km/sec then it increases abruptly to 8 km/sec and further at 2 900 metres it reaches its maximum of 13 6 km/sec after which it drops to 8 1 km/sec and then gradually rises to 11 3 km/sec

On the basis of a study of earthquakes and a determination of the mass and average density of the Earth it is assumed that the Earth consists of the following inner shells

(geospheres) which differ from each other in composition and condition of matter

1 The upper shell—known as the Earth s crust (litho sphere) Its thickness on continents is from 30 to 40 kilom etres under mountain ranges up to 70 kilometres under the Atlantic and Indian oceans from 10 to 15 kilometres, and in the central part of the Pacific Ocean up to five kilometres The composition of the upper parts of the lithosphere differs from that of the lower deeper zones In the upper part of the lithosphere there is a predominance of oxygen (O), silicium (Si) and aluminium (Al) In the lower levels magnesium (Mg) supplants aluminium The Earth's crust is composed of rocks which are common on the surface The density of these rocks does not exceed 3 4

2 The intermediate shell (mantle) is believed to spread to a depth of 2 850 2,900 kilometres In the composition of the upper part of the mantle Fe, Si and Mg play an important role while Cr is of lesser importance In view of this the upper layer is called the *crofesima* The density of the matter in it ranges from 4 to 5 Its depth varies from 1 200 to 1 250 kilometres Downwards in the composition of the mantle an essential role is played by Ni and the lower layer of the mantle is therefore called the *nifesima* The density of the matter in this layer varies from 5 to 6

3 The Earth s core within which an inner core is distinguished The upper boundary of the inner core lies presumably at a depth of 5 000 kilometres It was previously supposed that the core was composed of iron nickel and other heavy metals, and was called *nife* At present it is believed that the core differs from the overlying shells by the state of the matter rather than by its composition Under the high pressure prevailing in the core, the matter, which is of a silicate content, is in a metallised state This means that under the influence of pressure the atoms were partially destroyed and lost a certain quantity of their electrons

There is another change in the physical properties of matter at the border of the inner core, it is not unlikely that this change is linked with the detachment of a still greater number of electrons from the atomic systems The density of matter composing the core varies from 6 to

12 This geosphere is also called the barysphere or heavy sphere

Pressure grows very rapidly with depth At a depth of one kilometre the pressure is 27.5 atm at 70 kilometres 18 900 atm at 1 200 kilometres 403 100 atm and at 2 900 kilometres 1 213 100 atm in the centre of the Earth the pressure is approximately 4 163 450 atm

Magnetic Properties of the Earth The Earth possesses magnetic properties a fact that has been known to ancient peoples who learned to use a compass A magnetic needle was used for practical purposes for the first time by the Chinese three thousand years ago In Europe the compass has been in use since only the twelfth century and the study of the Earth s magnetic properties began in fact at the end of the eighteenth century

The *Earth s magnetism* is characterised by two values magnetic declination and magnetic inclination

Magnetic declination is the angle between the direction of the magnetic needle and the geographic meridian and can be eastern or western It differs at various points A line on a map joining points with the same magnetic declination is *called an isogon (or an isogonic line) A zero isogon of declination* is called a magnetic meridian Like the geographic meridians isogonic lines converge on one point in the north and south but these points do not coincide with the geographic poles the coordinates of the North Magnetic Pole are 70 5 3 N and 96 45 3 W and those of the South Magnetic Pole are 75 6 S and 154 8 E We cannot say definitely why the magnetic poles do not coincide with the geographic poles but it is presumed that this is due to the uneven distribution of land and water

Magnetic inclination is the angle of inclination of the magnetic needle towards the horizon in the Northern Hemisphere the north end of the needle inclines to the horizon and in the Southern Hemisphere the south end inclines to the horizon The inclination varies at different points The lines joining points of equal inclination are called isoclines (isoclinal lines) The magnitude of inclination increases from the equator towards the poles and reaches its maximum at the magnetic poles where the needle comes to rest in a vertical position Isoclines pass at a right angle to the isogons The

grid of magnetic isoclines and isogons thus does not coincide with the geographic grid of latitudes and longitudes

The magnitudes of inclination and declination vary in time This includes diurnal annual periodical (at regular intervals lasting for a number of years) and secular variations These variations are apparently associated with the Earth s position in relation to the Sun this position changes in the course of twenty four hours years and centuries Some scientists believe that the variations in the Earth s magnetic properties are due to changes in the state of the Sun

In some places of the Earth the direction of the isoclinic and isogonic lines undergo definite variations which are linked up with *magnetic anomalies* It has been ascertained that magnetic anomalies are caused by large masses of magnetite (magnetic iron ore) or ferruginous rocks lying relatively close to the surface of the Earth They can also be caused by strong displacements—fractures in the Earth s crust—which throw rocks with different magnetic characteristics into contact with each other

In addition to the magnetic declination and inclination, it is also important to determine the intensity of the geomagnetic field which has different values in various places and changes depending on the Earth s position in relation to the Sun

Parallel with regular diurnal variations of magnetic elements (inclination declination and intensity) sudden variations of the magnetic needle, going far beyond the limits of diurnal variations are sometimes observed These variations of the needle register disturbances in the geomagnetic field called magnetic storms Magnetic storms are, as a rule short-lived but they sometimes last for several days A study of magnetic storms has shown that they either accompany volcanic eruptions arise with thunderstorms or are linked up with earthquakes

Knowledge of the Earth s magnetic properties is utilised in geophysical prospecting for mineral deposits (magnetometry) simultaneously with gravimetric and other methods

Thermal Properties of the Earth The Earth possesses a definite amount of heat external heat from the Sun and internal heat from the Earth s interior

The Earth receives an annual average of 10^{21} large calories of heat from the Sun No two points on the Earth re

ceive the same amount of heat from the Sun because this depends on the force of radiant energy (insolation), and, to a large extent on several other factors the uneven distribution of land and water, which possess different heat absorption and radiation capacities (the difference between a maritime and continental climate) the crustal relief (for every 100 metres of elevation above sea level the temperature drops by 0 5°) the development of vegetation (an absence of vegetation causes steep fluctuations in the soil temperature) and air and ocean currents

It is nevertheless possible to establish points on the Earth s surface with identical mean annual or monthly temperatures This enables us to compile temperature charts consisting of isotherms—irregular curves which diverge, sometimes very greatly from latitudinal lines

In the Northern Hemisphere the mean annual temperature is 15 5° C and in the Southern Hemisphere 13 6 C The mean annual temperature of individual points in each hemisphere declines in the direction from the equator towards the poles

The polar regions have a very low mean annual temperature from —10 to —15 C and sometimes lower In these regions the rock series with negative temperatures (permafrost) are of considerable thickness A temperature of —3 7° C was recorded at a depth of about 275 metres in the lower course of the Ob River In some places permafrost reaches down to a depth of more than 600 metres

When we observe the thermal properties of the upper levels of the Earth we find that these levels are heated in summer and cool in winter the temperature fluctuations are stronger near the Earth s surface where they sometimes are as high as 100 C For example in the deserts of Central Asia the summer temperature of the heated soil is higher than 70 C while in winter it falls to —30 C or lower However with depth the temperature fluctuations decrease and at a certain depth they disappear entirely This is the zone of constant annual temperatures In this zone the soil temperature is equal to the mean annual temperature of the air on the Earth s surface Overlying this belt is the heliothermal zone which consists of strata of the Earth s crust that feel the influence of radiant energy

In various places the zone of constant temperatures is situated at different depths This depends on the extreme values of the surface temperature and on the thermoconductivity of the rocks The more the temperature fluctuates and the higher the thermoconductivity of the rocks the deeper is the zone of constant temperature situated In some places this zone lies at a level of one or two metres below the Earth s surface and in the others at depths of over 40 metres In Paris for example it lies at a depth of 28 metres, and in Kirovograd at a depth of 19 2 metres

Below the belt of constant temperatures is the geothermal zone, where the temperature regularly rises and depends not on radiant energy but on heat from the interior of the Earth

It is now considered that this heat is chiefly of radioactive origin however from the standpoint of some cosmogonical hypotheses (those of Laplace Fesenkov and others) it may also be explained as relict (residual) heat from the astral stage of the Earth s development

The rise of temperature with depth is not the same at different points of the Earth In the regions of active or extinct volcanoes the temperature rises very rapidly 1 C with about every 4 5 metres of depth In regions remote from volcanic manifestations the temperature rises much slower, averaging 1° C with every 33 metres of depth The average depth in metres within the Earth s crust corresponding to an increase of one degree in temperature is called the *geothermic degree* the increase in temperature in degrees per 100 metres of depth is called the *geothermal gradient*

Temperature readings have been taken in numerous deep boreholes Different temperatures have often been recorded at the same depth at various points As an example here are the temperature readings from a deep borehole in the North Caspian region

at 500 metres—42 2° C
" 1,000 metres—55 2° C
" 1 500 metres—69 9° C
" 2 000 metres—80 4° C
" 2 500 metres—94 4° C
" 3 000 metres—108 3 C

A temperature of 41 C has been recorded in a deep bore hole in Moscow at 1 630 metres while in the vicinity of Tashkent a temperature of 55 C has been recorded at 900 metres In some boreholes reaching to a depth of three kilometres and over a temperature of more than 100 C has been recorded *The geothermic degree in the upper strata* of the Earth s crust in the U S A varies from 35 to 45 metres in Western Europe from 28 to 36 metres in the U S S R from a few metres (for example in the Mineralnyye Vody area) to a hundred metres The differences in the geothermic degree are caused by the following

1) The different thermoconductivity of rocks the higher the thermoconductivity of the rocks composing the Earth s crust area the smaller is the geothermic degree and vice versa

2) The hydrochemical processes in the rocks One of these processes is the interaction reaction between water and fer rous sulphides (for instance pyrite) which liberates large amounts of heat

The interaction reaction between water and sulphides is widespread in regions of oil and coal fields because the clays and limestones in these regions very often contain large quantities of ferrous sulphides in these areas the geothermic degree as a rule decreases accordingly For example in the Grozny oilfields the geothermic degree is 20 25 metres and in the Baku oilfields it is 23 28 metres

3) The conditions in which rocks occur In folded bedding where the beds dip steeply or are vertical the increase in temperature with depth is much faster than in horizontal beddings This is due to the nearness of the heat carrier beds to the surface

4) The action of ground waters Streams of hot subterra nean water heat the rocks and thereby decrease the geo thermic degree cold streams reduce the temperature of rocks even at relatively great depths

5) The action of surface waters Near an ocean or sea the geothermic degree will be higher and on the continent far from bodies of water it will be lower because huge masses of water have a cooling effect on the geothermal conditions of the area

6) The concentration of radioactive elements in rocks In areas with a high concentration of radioactive elements the heat liberated by the decay of these elements causes the geothermic degree to drop

Investigations of geothermal conditions of the Earth s interior are of great practical importance The high temperatures must be taken into account when tunnels deep pit shafts and other underground projects are built In many cases in projects involving deep driving the temperature has to be lowered artificially In other cases as in Italy the heat of the Earth s interior (vapours thermal springs and so on) can be exploited commercially

Investigations of the temperature conditions in the Earth s interior are of great theoretical interest as well

Provided the geothermic degree of 33 metres accepted for the upper parts of the crust is maintained we can compute the temperature in deeper zones at 33 kilometres the temperature must be 1 000 C, at 50 kilometres—1 500 C and at 66 kilometres—2 000 C

It is known that very many minerals and rocks melt at such temperatures For instance quartz melts at 1 700° C felspars at 1 500 C olivine diabase at 1 150° C and flows freely at 1 225° C basalt flows at 1 170 C Consequently at normal pressure all rocks should be in a molten state in the lower part of the Earth s crust But the high pressure (11 000 14 000 atm) at these depths keeps the rocks in a solid plastic state

Below the crust the geothermic degree should increase sharply because otherwise the temperature in the centre of the Earth would be 193 060 C and the substance of the core and mantle would be in a liquid state Under these conditions the relatively thin crust could not remain solid and would melt as well Hence it may be inferred that the temperature in the bowels of the Earth is not higher than 3 500°-4 000 C Taking into consideration that there is a pressure of 4 163 450 atm in the Earth s core it is assumed that the substance composing the core and that of the mantle is in a solid plastic state This conforms with astronomical and seismological data

At present it is considered that the heat warming the solid crust comes from the decay of radioactive elements The geo

logical processes in the sialic and partially in the upper layers of this zone are to a large extent, associated with this heat The substance which melts under the action of radioactive elements thus increases in volume and this may result in an eruption of the liquid mass

OUTER GEOSPHERES OF THE EARTH

Among the outer geospheres of the Earth there are three shells a) a water envelope (the hydrosphere) which is represented by the oceans, seas rivers and ground waters b) a gaseous or air envelope (the atmosphere) and c) a sphere of life (the biosphere) which is closely connected with the atmosphere the hydrosphere and the lithosphere All these spheres are of great geological significance because they are very mobile and play a big role in the transformations that take place in the Earth s crust

THE ATMOSPHERE

Composition and Thickness of the Atmosphere

The atmosphere is the outermost sphere of our planet Nitrogen (78 03 per cent) oxygen (20 99 per cent) argon (0 94 per cent) and carbon dioxide (0 03 per cent) predominate in the lower layers of the atmosphere the share of all the other gases comes to only 0 01 per cent

The surface of the lithosphere and hydrosphere is the lower boundary of the atmosphere But for practical purposes the atmosphere extends for a certain distance into the lithosphere filling all its hollows with the result that the composition of the subsurface air changes considerably For example in the upper soil the amount of carbon dioxide rises to 0 6 per cent With depth the amount of oxygen decreases sharply, and there is practically no oxygen in a free state at a depth of about half a kilometre

It is harder to define the upper boundary of the atmosphere *Some scientists believe the atmosphere extends for 1 000 kil*ometres In the upper layers it gradually rarefies and merges with interplanetary space—this is what makes it difficult to define its upper boundary

Certain natural phenomena enable us to make a fair judgment of the altitude of the atmosphere and of the properties of its upper layers Silvery clouds, which seem to consist of fine luminescent fibres attracted the attention of investigators long ago These clouds are so transparent that the stars are visible through them *It has been established that* they lie at an altitude of 70 90 kilometres and travel at a velocity of 40 80 metres per second

White hot meteors indicate that the atmosphere reaches an altitude of 160 180 kilometres Auroral displays are dispersed lights so faint as to be invisible by moonlight They are generally seen at a height of 100 kilometres, and sometimes even as high as 1 000 kilometres

The atmosphere is divided into three concentric shells 1) the troposphere which adjoins the lithosphere 2) the stratosphere which follows the troposphere and 3) the ionosphere the upper shell

The Troposphere About 70 75 per cent of the atmosphere falls to the share of the troposphere its average altitude is presumed to be ten kilometres But because of the Earth s rotation and centrifugal force it is 16 kilometres high at the equator and up to 10 kilometres high over the poles

The features of the troposphere are 1) changeable moisture content 2) extreme mobility of the air in horizontal and vertical directions sometimes accompanied by a vertical motion (cyclones and anticyclones), 3) a mean temperature drop of 0 6° C per 100 kilometres of altitude from the surface of the hydrosphere or lithosphere In this connection at the outer limit of the troposphere the temperature over the equator falls to —80° C and the mean temperature in this part of the troposphere is —55 C

Owing to its changeable content the moisture condenses to the state of clouds, rain or snow or is present in the troposphere in minute quantities The maximum amount of vaporous moisture a cubic metre of air can actually contain depends on its temperature For instance at 0° C a cubic metre of air can contain 4 5 grams of water vapour, and at 25 C up to 23 grams

Among the air gases oxygen is of special importance The oxygen nitrogen ratio in the troposphere is most fa-

vourable for organic processes. When there is an increase of oxygen in the air the oxidation of organic matter in an organism proceeds with greater intensity when the oxygen content decreases the process of oxidation slows down

Changes of the nitrogen content in the air has no important bearing on organic processes In the upper layers of the atmosphere the amount of nitrogen increases and that of oxygen decreases

The content of carbon dioxide in the air is more changeable than that of oxygen and nitrogen Carbon dioxide accumulates in the air as a result of the oxidation processes in the outer spheres of the Earth and in the soil and also through emission from volcanoes mineral springs and so on Among air gases carbon dioxide is the heaviest and there is therefore more of it in the lower layers of the troposphere This gas is unevenly distributed in the horizontal direction as well For example there is almost twice as much of it over volcanic regions towns and industrial districts than over oceans and the polar regions Carbon dioxide is very important it is the basic material for the nutrition of plants Moreover it is a thermal insulator which tends to prevent the Earth s heat from being radiated into outer space It is believed that if carbon dioxide were to disappear from the troposphere the mean annual temperature of the air over the Earth would drop by 21 C from the present 14 C and that if the amount of carbon dioxide were to double the mean temperature would rise by 4 C

The troposphere contains a large amount of dust On the average there are 250 000 of dust like particles in a cubic centimetre of air Dust rises when the wind blows dry particles of mineral matter and sea spray from the surface of the Earth it also forms in the process of the combustion of wood coal and meteorites and during the eruption of volcanoes Spores bacteria and other minute organisms are often essential elements of atmospheric dust The amount of dust in the troposphere is naturally much greater over continents than over seas it is greater over arid regions than over the regions with abundant moisture and dense vegetation the amount of dust over areas covered by snow drops to a minimum Dust dims the troposphere and slight

ly weakens the insolation of the Earth's surface Minute dust particles are possibly nuclei, or centres around which water vapour condenses to produce clouds fog, frost dew, rain snow and hail

The Stratosphere The troposphere is enveloped by the stratosphere Between these two shells there is a one or two kilometre thick intermediate layer which is sometimes called the substratosphere The stratosphere differs from the troposphere in that in it we observe air masses moving exclusively in a horizontal direction Stratospheric air has zero humidity and consequently there are no clouds As far as the temperature conditions in the stratosphere are concerned, a constant temperature is observed up to an altitude of about 25 kilometres above this zone the temperature continuously rises At 10 25 kilometres it is approximately —25° C, at 40 kilometres—0°, and at 70 kilometres—about 35° C

It is believed that in the stratosphere, at an altitude of 15 to 35 kilometres there is a concentration of ozone a very small amount of which is found in the troposphere The major portion of ozone roughly 30 per cent is concentrated in the stratosphere at an altitude of 25 to 30 kilometres

The Ionosphere The ionosphere begins at an altitude of 75 80 kilometres After studying the spectre of the Polar Lights the light of meteorites passing through the iono sphere and other phenomena, scientists have come to the conclusion that due to the action of ultra violet and cosmic rays the air in these layers of the atmosphere is ionised The more the air is ionised the greater is its electrical conductivity The degree of ionisation is different in the various levels of the ionosphere Two ionisation maxima are identified 1) the Kennelly-Heavyside layer at an altitude of 100 kilometres and 2) the Appleton layer at an altitude of 250 kilometres

The processes in the stratosphere and ionosphere have been very inadequately studied, but there are grounds for believing that they strongly influence terrestrial magnetism the Earth s electric field and so on A study of the high layers of the atmosphere is therefore of particular interest from the geophysical point of view

In addition to oxygen and nitrogen, a considerable amount of helium appears in the composition of the atmosphere beginning at an altitude of 75 kilometres A great amount of hydrogen is found in the level beginning at an altitude of 90 kilometres while in the level beginning at an altitude of about 140 kilometres the atmosphere consists entirely of *helium and hydrogen* The hydrogen content in the atmosphere increases to 90 92 per cent at an altitude of about 500 kilometres

Dynamics of the Troposphere As a result of the continuous movement of air in the troposphere the relative composition of gases in it is nearly constant This continuous movement is due to the different temperature and atmospheric pressure at various points of the Earth s surface caused by solar radiation

The transformation of radiant solar energy into thermal energy is a very complex process The most important factor influencing thermal processes on the Earth is the angle of incidence of the solar rays in different parts of the Earth s surface This angle depends on the relief of the Earth s surface and on the seasonal changes The distribution of solar energy is further complicated by the fact that it takes place not only on the Earth s surface but also within the troposphere whose thermal conductivity is as we now know inconstant

Air movement leads to a heat exchange between the high and low latitudes of the Earth and between the different layers of the troposphere Generally air moves from high to low pressure regions Several factors are responsible for atmospheric pressure variations on the Earth and for the direction in which air (winds) moves

The principal factor is the unequal heating of the Earth s surface and the transfer of this heat to the air Heat causes air to expand making it lighter and thus giving it a tendency to rise over the heated surface of the Earth

But having risen to a high altitude in one area it g[illegible] ly cools and grows heavier [illegible] e result that it [illegible] move back towards the s[illegible] Earth This to circulation wa[illegible] air [illegible] s while c[illegible] scends to the E[illegible] t [illegible] rizontal m[illegible]

which we call a wind As we have already stated air moves from regions of high pressure to regions of low pressure and the greater the difference in pressure the faster this movement becomes At times the air moves horizontally over large territories

There are winds of a planetary scale which manifest themselves over vast areas of the Earth and are characterised either by a constancy of direction (trade winds) or by directions that change with the season (monsoons) and local winds blowing over limited areas—the Central Asian Afghan and the North Caucasian Bora" for example

Fig 3 Diagram of a cyclone in the Northern Hemisphere

Moreover winds may originate in different areas as a result of a temporary change in atmospheric conditions

Cyclones and Anticyclones There are two principal types of the air movements cyclonic and anticyclonic

Cyclones are masses of air circulating (in the Northern Hemisphere) in a counter clockwise direction the minimum air pressure is observed in the centre of these rotating masses of air (Fig 3) Anticyclones are masses of air circulating (in the Northern Hemisphere) in a clockwise direction with the highest air pressure in their centre In a mass of air moving in a cyclonic pattern the atmospheric pressure thus gradually increases from the centre towards the periphery while in anticyclonic air masses the pressure gradually drops from the centre towards the periphery

A cyclone generally moves at a high progressive speed of several score of metres per second As a cyclone with a progressive speed of 70 metres per second (or 260 kilometres per hour) passes over the sea it churns up the water and

tears sprays from it with the result that a rotating pillar of water forms in the centre of the moving cyclone. Because of their very high velocity, cyclones give rise to waves and currents that at times cause great destruction. For example, as a result of the cyclonic activity of air masses in a westerly direction there have been disastrous floods in the mouth of the river Neva which drains into the Gulf of Finland. Since 1707, the year Leningrad was founded, the water in the Neva has risen above its normal level more than 300 times. Especially big floods were recorded in 1777 (when the water rose by 3.3 metres), in 1824 (3.68 metres) and in 1924 (3.62 metres). At these levels the water flooded up to 65 square kilometres of the city.

Other littoral areas have also been the scene of devastating floods caused by cyclones. In 1932 the town of Santa Cruz, Cuba, was destroyed by gale-whipped waves and nearly 2,500 people perished. In 1737 in the Bay of Bengal a flood caused in the mouth of the Hugli River by gale waves took a toll of 3,000 lives; over 50 thousand lives were lost in the flood of 1864 in the same area. Floods of this nature are especially terrifying when the water moving with the cyclone gets into a bay, a river mouth or some other narrow space.

Tropical cyclones have been known to transport rather heavy objects over considerable distances. For example, in 1831 a piece of lead weighing about 65 kilograms was transported on Barbados over a distance of half a kilometre. In 1780 on the same island a stone fort was destroyed by a hurricane and heavy cannons were carried dozens of metres. Cases have been recorded of loaded railway cars being derailed by cyclones and ships torn from anchor and cast ashore.

In temperate latitudes cyclones move at a lesser speed but in these areas as well their force is often considerable. A unique "rain" of silver coins minted in the sixteenth-seventeenth century fell from the sky during a violent thunderstorm accompanied by hurricane winds and hail in the vicinity of Meshchera village, Gorky Region, the U.S.S.R. The cyclone must have rooted out a treasure trove and carried away the light silver coins (this case has been described by S. Kalesnik).

Precipitation Before water vapours can condense in the atmosphere, they require the corresponding humidity (100 per cent) and the presence of condensation nuclei These nuclei are particles of dust floating in the troposphere When moisture condenses clouds appear in the atmosphere, and any disturbance in the equilibrium of the moisture in the clouds leads to precipitation in various forms

The amount of precipitation for any particular period of time is measured by the layer (in millimetres) of water, which would have formed on the Earth's surface if the water had not seeped into the soil, evaporated or flowed into a lower-lying area Moscow has a mean annual precipitation of 586 millimetres

Precipitation is distributed very unevenly over the Earth as a whole In some regions it is insignificant, in the deserts around the Aral Sea, for example, the annual precipitation sometimes approaches zero, and the total precipitation over a period of many years does not exceed 150 200 millimetres a year In other places precipitation is more abundant, in the Batumi area the Caucasus for instance the mean annual precipitation reaches 2,400 mm

Observations show that precipitation depends first and foremost on the proximity of the area concerned to the sea Some maritime regions however have very little precipitation as for example the Thar Desert in India over which masses of air sweep without rainfall, but on reaching the windward slopes of the Himalaya foothills they cause enormous precipitation (12 500 millimetres a year)

Weather and Climate In every area and at any particular moment the air temperature its pressure relative and absolute humidity*, cloudiness and so on change rather quickly This changeable state of the meteorological elements of the atmosphere is known as weather

The weather is the state of climatic factors in a given area and at a given moment At one and the same moment

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* The absolute humidity is the mass of water vapour in a cubic metre of air It is measured in grams or according to the elasticity of water vapour in a milimetre of Hg pressure

Relative humidity is the ratio of the actual amount of water vapour in a given volume of air to the amount which would be present if *the air were to be saturated without* any change in temperature

the weather may be different in various places In one and the same area the weather often changes in the course of a few hours

In contrast to this the change in the average state of the climatic factors over many years is called the climate The climate is more constant than the weather but over a long period of time it also undergoes variations

The principal factors controlling the climate are the geographic latitude the distribution of land and water the topography characteristics of the prevailing air mass the vegetative cover and lastly the activity of man who remakes the vegetative cover and soils builds big cities water reservoirs and so on

In the U S S R the climate of the territories in the temperate and polar latitudes may be grouped as follows

1 Sea polar air whose features are a high humidity the whole year round relatively heavy precipitation and even distribution of this precipitation The mean annual temperature is approximately 7 10 C with an annual amplitude of 6 14 C The winter is relatively warm and the summer is cool This climatic zone embraces the north western end of the Soviet Union (Kola Peninsula and the Murmansk coast)

2 Transforming sea polar air which is also characterised by relatively heavy precipitation the whole year round but with a notable increase in the month of July The mean annual temperature is 9 C with an annual amplitude of about 20 C The entire western half of the European part of the U S S R lies in this climatic zone

3 *Continental polar air* The mean annual temperature is about 1 C with an annual amplitude of 39° C The winter is severe and the summer hot there is little precipitation, the maximum being confined to the summer months This climate is typical for the major part of the U S S R

4 Monsoon climate of the temperate latitudes This climate prevails in the Far East Its features are cold continental polar air in winter and sea polar air in summer The summers are rainy and moderately warm The mean annual temperature is 0 2 C with an annual amplitude of 25 34 C

5 Subpolar zone Here polar air prevails in summer and Arctic air in winter

6 Polar zone Arctic air predominates all the year round Annual precipitation does not exceed 200 300 millimetres

The climate as all phenomena in nature, gradually changes It has so to say its own history, which is linked up with the history of our planet There are many facts to show that the climate changes sharply In the U S S R such facts have been collected by M Bogolepov who showed the rhythmic character of the changes from damp to dry periods and vice versa There have been very sharp changes in the climate of the Arctic in the past 15 20 years The mean annual temperature during this period rose in Spitsbergen by 2 C, in Greenland by 2 5° C, in Franz Josef Land by 3 5 C while below the Arctic it rose in (Lenin grad for instance) by only 1° C The weather grew warmer chiefly through a rise of winter and autumn temperatures the spring and summer temperatures did not increase as much

Interesting temperature changes were recorded during the drifts of the *Fram* (1894 95) and the *Sedov* (1938 39) In the course of a period of 44 years the mean annual tem perature in the Barents Sea rose by 6° C This brought about essential changes in the outlines of some islands For example Vasilievsky Island in the Laptev Sea consisting of frozen sandy argillaceous rocks and marked on the map of 1912 melted away and by 1936 only a sand bank remained in its place Some of the adjacent islands grew shorter Semenovsky Island which was 15 kilometres long in 1823, shortened down to five kilometres by 1912 and to two kilo metres by 1936 The rise in temperature also affected ma rine fauna and flora For instance during this period cod appeared for the first time in commercial quantities off the coast of Spitsbergen and Norway

Fossil soils indicate that there have been climatic changes in the geological past The tropical lateritic soils of the Amur region over which lie podsolic and boggy soils that formed during the present cold climate are an example Climatic conditions leave their mark on the relief as well For instance an indication of the former glaciation of an area is the pattern of the valleys in it roches moutonnees sheep back rocks and other (small) forms of relief whose origin is due to the action of inland ice, also exemplify this

Animal and plant fossils also illustrate the nature of the climate. The remains of poplar, nut tree, hornbeam and oak have been identified in ancient deposits on the north shore of the Aral Sea. These plants, which could not have existed in desert conditions, point out to the nature of the forests in this region in ancient times. The juniper is the only conifer growing in Greenland today, but more than 28 species of Tertiary plants, including pine trees, cypresses and deciduous trees (bay trees, magnolias, oaks and other species of thermophilic plants) have been identified among fossil remains. Thermophilic plants (bay trees, magnolias and so on) have also been found in the Tertiary sands and sand stones of the area around Moscow.

Lastly, the rock structure illustrates the climatic conditions of the remote geological past. We know a whole series of deposits that are typical of the regions embraced by continental glaciation, for example, boulder clay, which represents glacial moraine deposits, varved clays, outwash sands, and so on*. In desert regions we find rocks with a surface coating of "desert varnish". Coals are an indication of a warm and humid climate.

Geologists thus have at their disposal facts that give them an idea of the climates of the geological past.

THE HYDROSPHERE

Land and seas are distributed very irregularly on the Earth's surface. The surface of our planet has a total area of about 510 000 000 square kilometres, of which 361 000 000 square kilometres (71 per cent) are occupied by seas and 149 000 000 square kilometres (29 per cent) by land. The water area is thus about 2.5 times bigger than the land area. However, it should be borne in mind that the average thickness of the hydrosphere in comparison with the thickness of the lithosphere, and all the more its volume in comparison with the volume of the whole planet, are extremely small. The average depth of the ocean is about 3.7 kil-

* More detailed information on glacial deposits can be found in the chapter *Snow and Ice as Geological Agents*.

ometres, which is equal to about 1 1,600 of the mean terrestrial radius while the ratio of the volume of water in the ocean to the volume of the planet as a whole is approximately 1 [illegible] 000

Land is concentrated mainly in the Northern Hemisphere, where it occupies 39 per cent of the surface in the Southern Hemisphere only 19 per cent of the surface is occupied by land This distribution of land and seas has brought a number of vitally important factors to the fore, one of them is the climatic characteristic of the continents

The World Ocean and Its Divisions The water surface of our planet called the oceanic surface, is generally considered as a common surface Y M Shokalsky named it the World Ocean In the World Ocean we can identify separate parts each of which has, to some degree, its own water temperature salinity, sea currents and conditions of glaciation Taking these features into consideration we distinguish in the World Ocean the Atlantic Ocean the Pacific (or Great) Ocean and the Indian Ocean

The Atlantic Ocean with all its seas occupies an area of 93,400 000 square kilometres It is bordered in the east by the coasts of Europe and Africa, in the west by the coast of America and in the south by the coast of the Antarctic continent Within the water surface, the boundaries of the Atlantic Ocean are defined by the meridian of Cape Horn in the west and by the meridian of Cape Agulhas in the east

The Pacific Ocean has an area of 179 700 000 square kilometres In the east it is bordered by the coast of Amer ica and by the meridian of Cape Horn in the south by the Antarctic continent and in the west by the coast of Asia Along the line formed by Sumatra and the islands located farther south the boundaries of the Pacific and Indian oceans are contiguous

The Indian Ocean occupies an area of 74,900 000 square kilometres It is bordered in the north by Asia, in the west by Africa, by the meridian of Cape Agulhas in the east and by the west coast of Sumatra Java Australia and Tas mania and the meridian of South Cape in the west Its south ern boundary is the coast of the Antarctic continent

The Arctic Ocean is also included in the group of oceans It occupies a surface of 13,100 000 square kilometres This

small ocean is bordered by the northern shores of Europe Asia and America The Arctic Circle is generally accepted as its boundary with the Atlantic Ocean

Seas In view of the fact that the continents have a very complex outline and an extremely jagged shore line the ocean occasionally cuts very deep inland This has led to the rise of outlying divisions of the ocean which are commonly called seas (the Black Sea the Sea of Marmora the Arabian Sea the Sea of Japan the Bering Sea and so on)

Of the seas linked up with the ocean there are inland and marginal seas The first cut deep inland are situated between two or several continents and occasionally have one or several narrow branches many of these seas are characterised by great depth The deepest among them is the Mediterranean Sea which is situated between Africa Europe and Asia and has two branches—the Sea of Marmora and the Black Sea The Red Sea situated between Africa and Asia is of the inland type

Marginal seas are sections of the submerged continental shelf Examples of such seas are the Sea of Okhotsk, the Bering Sea and the North Sea Some marginal seas also cut deep into the continents where they form inland basins the White and the Baltic seas for instance

World Ocean Floor The ocean does not have an even floor in some cases the irregularities are very considerable and form a very complex relief The best example of this in the Atlantic Ocean A submarine ridge in the shape of the letter S is known to exist on its floor This ridge extends from north to south in a narrow strip in almost the middle of the ocean The shallowest areas are in the northern part of the Atlantic Ocean between Ireland and Labrador there the average depth is about 2 500-3 000 metres Numerous telegraph cables between North America and Europe lie on the floor precisely in this part of the ocean, whence it received the name "telegraph plateau"

The outline of the submerged ridge repeats the contours of both North and South Americas on the one hand and the contours of Africa and Europe on the other In some places the ridge rises over to a considerable height the floor coming close to the water surface in the central part Here the

rated from each other by groups of islands Here the broad est shallow embracing the Barents Kara Laptev East Siberian and Chukotka seas stretches from the Eurasian coast to the central part of the ocean The depth of the shallow does not as a rule exceed 25 50 metres

Along the coast of America especially north of Alaska the shallow is narrower In this area there is a large number of big and small islands separated by a labyrinth of narrow straits

The central part of the Arctic Ocean is occupied by a deep trough (over 3 000 metres) near the North Pole it is 4 290 metres and farther south 4 000-5 000 metres deep The deepest point in the Arctic Ocean measures 5 182 metres The Lomonosov Ridge is in the Arctic Ocean and its con figuration and position are being studied by Soviet Arctic stations

Chemical Composition and Physical Properties of the Wa ters of the World Ocean Practically everywhere the ocean ic waters have an identical chemical composition their salinity averages 3 5 per cent or 35‰ (per mile) i e 35 grams of different salts are dissolved in a litre of water The salt content is higher in inland seas where there is no inflow of fresh water and evaporation is intense in the Red Sea for example the water has a salinity of 4 2 per cent Where sea water is diluted with fresh river water salinity appreciably drops in the Baltic Sea and in the Sea of Azov for example the water has a salinity of only 1 1 2 per cent Near the mouths of big rivers flowing to the sea the water is almost fresh as for instance in the mouth of the Neva River in the eastern part of the Gulf of Finland On the other hand in some inland basins Ka ra Bogaz Gol for example salinity reaches a concentra tion point at which salt begins to precipitate from the solu tion

Sodium chloride predominates (78 32 per cent) in the composition of sea water then follow magnesium chloride (9 44 per cent) magnesium sulphate (6 4 per cent) calcium sulphate (3 94 per cent) potassium sulphate (1 [illegible] per cent) calcium carbonate (0 04 per cent) and silica (0 009 per cent) Bromine iodine manganese zinc lead copper and gold have been found in minute amounts However some of

these elements are of great biological importance iodine is assimilated by certain algae and copper by certain molluscs Iodine is produced from algae in large quantities but its extraction directly from sea water would be a matter of considerable difficulty

Sea water also contains gases chiefly oxygen and carbon dioxide, ammonia occurs frequently In seas, where the run off into the ocean is hindered, as in the Black Sea for example where the outflow is barred by the Bosporus submerged sill hydrogen sulphide accumulates on the bottom it is a product of the decomposition of organic remains and the transformation of sulphurous compounds In the Black Sea for example, at a depth of 183 metres the water is so saturated with hydrogen sulphide that no organic life is possible Only certain species of bacteria can exist in these conditions

The surface temperature of oceanic water depends on the geographic latitude and the season and varies from —3°C in winter at the poles to +32 C in summer at the equator The mean annual temperature of the ocean surface is 17 4°C and in the lower layers of the atmosphere round the Earth the mean temperature is 14 4°C The hydrosphere is, consequently a powerful source of thermal energy for the Earth s atmosphere The warm surface layer of water as *temperature readings show is relatively thin 100 150 metres* The temperature of water decreases with depth At a depth of 750-1 100 metres its temperature is 4 C while near the ocean floor the temperature varies from —2 C (in the polar regions) up to 2 C In land-locked seas the temperature of deep water is higher in the Mediterranean, for example it is 12 C at a depth of 2 500 metres

The density of water in the ocean varies from 1 0275 in the region of the trade winds where there is intensive evaporation to 1 255 in the region of the doldrums and the belt of heavy rainfall (along the equator), as well as at the poles From the surface downwards to a depth of about 200 metres the density of water increases and has a salinity of 37 grams per litre farther down to a depth of 1,800 metres salinity gradually decreases and near the bottom it slightly increases again A change in the density of water is accompanied by a change of its salinity

The pressure of sea water increases by one atmosphere per 10 metres of depth with the result that in the deep troughs it is more than 1 000 atmospheres. Pressure plays an important role in the distribution of marine life

Sunlight penetrates into water to a depth of about 200 metres With photofilms, sensitive to chromatic rays of the spectrum, it has been established that ultra red rays do not penetrate deeper than 400 metres and that ultra violet rays act upon photofilms even at a depth of 800 metres Since plants require sunlight their occurrence is mainly restricted to depths of up to 200 metres which are typical for the shallow seas around the continental shelves

The waters of the World Ocean are in constant movement as a result of wind action and the attraction of the Moon and Sun Moreover in the hydrosphere there are what are known as run off and compensation currents which can scarcely be seen by the human eye The former are caused by the changes in atmospheric pressure in different parts of the ocean the latter are the result of evaporation fluctuations of the water temperature precipitation and the melting of polar ice

Winds set waves in motion The height of wind waves depends on the strength of the wind the duration of its action and the depth of the sea Small waves are 10 15 times longer than their own height and billows that reach a height of 15 metres in the open sea are 30 40 times as long as they are high The gradient angle of waves is from 2 8 to 5 7 Wave motion is oscillatory with each particle of water rotating about its axis rising over the wave crest and then dropping This can be very clearly seen during a swell when the sea is still heavy but the wind has fallen a boat rolls and pitches but moves only to the next wave crest

A strong continued breeze brings wave crests together blows white caps off their surface and throws floating objects from one wave to another The disturbance of the surface water is transmitted downward but even billows die away at a depth of about 200 metres the height of waves decreases in geometrical progression with depth

Complex transformations of sea waves caused by the proximity of the sea bottom and by collisions between on

coming and *reflected waves (breakers) are observed in off*-shore shallow waters As waves approach a shore they swash or break against it The shock stress of a swash pounding against the beach is occasionally (in the Black Sea) as high as 60 tons per square metre This accounts for the gradual wearing away of the sea shore This phenomenon is of vast geological importance and is known as marine erosion or wave abrasion

Constantly blowing winds (trade winds and monsoons) cause a movement of water known as sea currents One of the most powerful of the sea currents in the Atlantic Ocean is called the Gulf Stream This current originates in the equatorial part of the Atlantic under the action of the north trade winds This wind blowing from north to south as a result of the Earth s rotation approaches the equator at an angle of 45° Gaspard Gustave de Coriolis established a law under which the action of the wind on an aqueous medium (water masses) of the ocean starts an east west current along the equator *Near the coast of South America the current* is deflected into a northern direction and farther as it emerges from the Gulf of Mexico, it turns to the north-east

The Gulf Stream is a colossal river in water banks It has its maximum width of 275 kilometres off Florida It is more than 300 metres deep and has a rate of flow of three metres per second (for the sake of comparison let us recall that in flood time the rate of flow in the Volga is less than three metres per second)

The Gulf Stream is of enormous importance as a distributor of warm *waters brought from the south, and as a means* of making the climate of the northern coast of Europe milder Thus, thanks to the Gulf Stream the port of Murmansk does not freeze in winter whereas the port of Leningrad which is about 1 000 kilometres farther south, is ice bound for five months every year

A similarly warm current the Kuroshio passes in the Pacific Ocean south of the Kuril Islands The north and north west winds blowing from the east coast of the northern continents give rise to the cold Greenland and Labrador currents in the Atlantic and to the California current in the Pacific

There are rather strong sea currents between inland seas as well these currents owe their rise to a difference in water levels Thus fresh water flows along the surface from the Black Sea through the shallow Bosporus into the Sea of Marmora while salt water flows in the reverse direction along the bottom from the Sea of Marmora into the Black Sea There are similar currents between the Mediterranean Sea and the ocean between the North and Baltic seas, and so on

Due to the differential attraction of the Moon and the Sun there are tides along the shore These phenomena are due chiefly to the attraction of the Moon which is the nearest *celestial body to the Earth the attraction of the Sun* is only an additional factor Tides change twice a lunar day

The dynamics of tides are visualised as follows The Earth's hydrosphere is influenced by the action of two forces a centripetal force which binds the hydrosphere to our planet, and a centrifugal force which strives to tear it away from the Earth s surface Under the attraction of the Moon the hydrosphere is drawn from the Earth s surface in the direction of the Moon But the latter rotates about the Earth and consequently tries to carry away the drawn off surface of the hydrosphere

Let us imagine a section of the globe across the equator and the Moon on a prolongation of its equatorial radius travelling in an anti clockwise direction Attracted by the Moon the hydrosphere is drawn towards the Moon (tide) The rise of the hydrosphere due to the action of the centrifugal force is observed at the same time at the opposite side of the circle (also tide but fainter)

Ebb tides are observed on the ends of a diameter which is perpendicular to the first diameter As the Moon rotates the e two tides and ebb tides also shift their position and because of this the tides and ebb tides alternate twice at each point of the circle in the course of twenty four hours Tides coincide with the passage of the Moon through the meridian of a given point while ebb tides coincide with the Moon s rise and setting

A solar tide is 2 5 times lower than a lunar tide When the Sun and Moon are aligned on one side of the Earth their tidal forces combine and unusually high tides result

Similarly, when the tidal forces of the Moon and Sun are at a right angle to each other and hence opposed the tides are reduced to their lowest level

Tides reach their maximum height in equatorial regions—in the tropics and subtropics, northward and southward from the equator their height decreases On mid ocean islands a tidal wave is never higher than 2.5 metres but along continents it may reach a considerable height especially when it crowds into a narrow bay or strait Thus in the Straits of Magellan tides reach a height of 18 metres and in the Bay of Fundy Canada they rise as high as 21.5 metres Tides rise higher than normal during a favourable wind In the U S S R the highest tides occur in the neck of the White Sea and in the Penzhina Bay in the Sea of Okhotsk, where they reach the ten metre mark

Lakes On the continents the hydrosphere is represented by lakes, rivers and ground waters In the Soviet Union the largest lakes are

	Area (000 square metres)	Depth (metres)	Absolute height of water level (metres)
Caspian Sea	424 3	97[illegible]	−28
Aral Sea	63 8	68	+66
Lake Baikal	31 6	1 741	+45[illegible]
Lake Ladoga	18 4	230	+4
Lake Balkhash	17 [illegible]	26 5	+35[illegible]
Lake Onega	9 6	120	+33

Lakes are natural water filled inland depressions or reservoirs of various origin which have arisen a) as a result of the action of the Earth s internal forces—subsidences (Lake Baikal Issyk Kul and others) explosions during volcanic eruptions (crater lakes—Lake Kronotskoye in Kamchatka for example), b) as a result of the action of external forces—glacial scouring (Lake Ladoga) and rock falls that blocked up river valleys (Lake Sarez and Yashvl Kul in the Pamirs)—and the action of ground waters (cave or sink lakes—the Kungur Lakes for example) there are also man made artificial basins (Moscow Tsimlyanskoye Rybinsk and other seas) and sea built spits and baybars (lagoons, for instance)

There are running water lakes and lakes without outlet The former receive rivers and give rise to new rivers (Lake Ladoga Lake Onega) The latter receive rivers, and discharge their water solely through evaporation (Caspian Sea Aral Sea Lake Balkhash) The water in the former is fresh and in the latter it gradually salinises first becoming brackish (in Issyk Kul for example it contains 3 6 6 7 grams of salt per litre in the Aral Sea 10 4 12 9 grams, in the Caspian Sea 13 14 grams) then salty and salt brine (in Lake Iletskoye for example the water contains 155 2 grams per litre in Kara Bogaz Gol 163 9 285 grams, in Lake Baskunchak 284 2 grams and in Krasny Liman [Perekop] up to 372 grams)

There are no tides in lakes but waves and currents occur Moreover seiches or oscillations of the surface linked up with changes in atmospheric pressure are observed

The water level and salinity in lakes vary depending on climatic conditions The temperature of lake water near the surface undergoes sharp seasonal fluctuations which gradually smooth out with depth Depending on the geographical conditions and salinity of the water extremely low temperatures are occasionally recorded in lakes In Lake Kupalnoye for example which is situated near the town of Iletsk the water (brine) temperature near the bottom falls to —13 C when ice covers the surface, and in Lake Koryakovo it drops to —27 C

Rivers Rivers represent atmospheric precipitation flowing on the Earth s surface and impounded into channels Where precipitation is abundant the network of rivers is denser No rivers rise in deserts The Soviet hydrologist A Voyeikov called rivers the product of the climate and classified them as follows 1) rivers fed almost completely by melted snow and ice 2) rivers fed only by rain water 3) rivers of mixed feeding Ground waters often contribute appreciably to the feeding of rivers

The land area from which all water is drained into the channel of a river is called the drainage basin The size of drainage basins the length of rivers and the quantity of water transported by them may be different Table 1 contains information on some rivers

Table 1

River	Basin area (000 000 square kilometres)	Length (kilometres)	Annual run off (cubic kilometres)
In the USSR			
Ob (with the Irtysh)	2 9	5 200	4 0
Yenisei (with the Selenga)	2 6	5 200	500
Lena	2 38	4 600	
Amur (with the Argun)	2 0	4 480	350
Volga	1 46	3 690	270
Danube	0 8	2 850	220
Dnieper	0 52	2 150	50
In other countries			
Amazon	7 05	5 00	160
Congo	3 6	4 200	1 890
Mississippi	3 25	6 600	550
Yangtze	1 8	5 200	680

There is a great number of rivers in the world In the European part of the U S S R alone there are more than 32 000

Rivers carry fresh water However in areas with an arid climate river water is sometimes brackish as for instance in the Atrek and the Sumbar West Turkmenia

The quantity of water in a river depends on the season In seasons of low alimentation (in the Soviet Union—winter) the quantity of water in rivers is small its level is low (low water) high water comes in spring when the water in a river reaches its highest level, we say the river is flooded During high water and especially during floods rivers overflow their banks sometimes with catastrophic results

The rate of flow in rivers varies greatly and depends on the inclination of the bed (river gradient) It increases in proportion to the square root of the gradient when the gradient quadruples the rate of flow doubles The moving force of a river depends on the mass of water in it and on the rate of flow and is expressed by the formula $\frac{Mv^2}{2}$ i e the moving force is proportional to the mass of water (M) and to the square of the rate of flow (v)

Thus the hydrosphere like the atmosphere is highly

mobile and has a moving force and is as we shall see below a powerful geological agent contributing to the transformation and development of the Earth s crust

THE BIOSPHERE

The geological role of organisms has been recognised by scientists long ago However it was not until the twentieth century that a scientist laid special emphasis on the role of organisms in the life of the Earth This was done by the Russian mineralogist and geochemist V Vernadsky who showed that between organisms and the environment there is a close interaction which manifests itself in a continuous migration of atoms from the inorganic world into living organisms and vice versa

The origin of life on our planet still remains unsolved It is supposed that the lower organisms which appeared in the very remote past could also have existed in thermodynamic conditions other than those obtaining today V Omelyansky gives interesting facts about the vitality of some lower organisms Certain fungal spores for example exist at a temperature of up to 140 C while the spores of microbes live at as high a temperature as 180 C and do not lose their viability Bacteria spores resist cooling equally well In liquid hydrogen they live for ten hours at a temperature of —253 C and at a temperature of —190 C they preserve their viability for about six months Microorganisms can survive enormous variations of pressure Some saprophytic fungi and bacteria for example can resist a pressure of up to 3 000 atmospheres and yeast can survive under a pressure of 8 000 atmospheres

Life on Earth is closely linked up with the atmosphere hydrosphere and lithosphere It can be said that it is in fact the function of these geospheres were one of them excluded from the composition of the Earth life in its present form would disappear Within the boundaries of our planet we find organisms in the atmosphere up to an altitude of six kilometres in the hydrosphere to the abyssal depths of oceanic troughs (10 170 metres) and in the lithosphere in layers at a depth of several hundreds of metres

The history of the Earth is generally divided into two big periods Azoic, when there was no life on Earth and Zoic when organisms appeared and began to develop intensively Since then the lithosphere has been continuously enriched by a number of minerals and rocks representing the result of the vital activity of animals and plants

The participation of organisms in the life of the Earth is not limited to the formation of minerals and rocks thanks to their vital activity, numerous important geological processes take place Complex biochemical reactions result in the formation of soils As far back as the beginning of the nineteenth century geologists rightly defined soil as a rock which differed from all other rocks by its fertility

From the geological point of view individual organisms play different roles Organisms are divided into a) rock forming and b) indifferent to rock formation All animals and plants are rock forming organisms

Among marine plants which play an important rock forming role mention must be made first and foremost of diatoms which have a silicified cell wall that persists as a skeleton after death and calcareous algae, which often appear as energetic reef builders Among the rock forming sea animals are foraminifera radiolaria sea mats corals echinoderms and bivalve mollusks

On land plants are the chief rock forming organisms Their vital activity results in the formation of caustobioliths (combustible minerals) sapropelites peat lignites coal and petroleum

The enormous role that organic matter plays in the life of the Earth depends on the vigorous activity of organisms Vernadsky has calculated that the entire mass of organic matter on the Earth makes up not more than 0 1 per cent of its crustal mass But through their activity organisms help to transport matter and in this respect their role according to the opinion of some scientists (S Kalesnik) is as important as the geological role of rivers the wind and glaciers

The propagation power of organisms is of great importance A female termite continuously lays thousands of eggs every 24 hours in the course of a life span that is some

4

times as long as nine years Dandelions engender such a numerous posterity that if it all survived it would cover the entire land area within 10 12 years Some fish lay several millions of roe and if enormous numbers of these eggs did not perish the hydrosphere would be congested in a very short span of time Here is another example diatoms propagate so energetically by gemmation that in eight days a single diatom could create a mass of matter that would be equal to the volume of our planet and an hour later this mass would double It would not be difficult to calculate how great this mass would be in twenty four hours Similarly in a year a ciliate infusorian (paramecium slipper animalcule) could create a mass of protoplasm that would be equal to the mass of our planet

However this extensive reproduction does not lead to any sizable increase of organic matter for the overwhelming majority of organisms perish in the embryonic stage Only those survive that are the most adapted to the surroundings The adaptability of organism to environment is due to the variability that each organism possesses under the influence of environment separate organs of the individual change constantly as they adapt themselves to the functions they must perform

The vegetable kingdom develops in definite conditions which are extremely diverse and may change in the course of the Earth s development One of the most important factors in the development of the vegetable kingdom is the climate The temperature humidity of the air gases topography (which determines the movement of air masses) sunlight and soil are of essential importance

Land animals are less dependent on climatic conditions than plants In particular this applies to warm blooded animals (for example birds mammals) Cold blooded reptiles and dipnoi can only live in definite climatic conditions (*temperate and warm climate*)

Orographic conditions also play a major role in the settlement of land animals Animals living in definite orographic conditions can be separated into groups These laws governing the distribution of land animals are of special importance when the animal kingdom of past epochs is studied

There is a fundamental difference between marine and land fauna First and foremost marine fauna badly adapts itself to more or less perceptible temperature fluctuations Marine fauna and flora are influenced by the salinity of sea water temperature currents sunlight water pressure floor relief and the composition of bottom sediments i e, by the entire complex of physical and chemical properties of the aqueous environment

According to their mode of life marine animals can be divided into the following groups benthos—fauna found at the ocean bottom nekton—free swimming organic life meroplankton—plankton living only part of the time at or near the surface plankton—passively floating animal life—and others

Oceans are densely populated down to a depth of 2 000 metres Below that level the number of planktonic and nektonic forms of fauna sharply decreases However various flora and fauna occur even in the deepest of the ocean troughs

The biosphere is the most active source of energy It sets huge masses of matter of the Earth s crust in motion Organic matter creates soil takes part in the formation of rocks influences the microrelief of the Earth s crust accumulates solar energy in the interior of the Earth and regulates the composition of the Earth s atmosphere All this shows that organic matter plays a considerable role and forces us to consider it as essential a geological factor as air and water

THE LITHOSPHERE

The lithosphere or the Earth s crust is a solid rocky shell It is subdivided into the upper zone of katamorphism and the lower zone of metamorphism In turn the upper portion of the katamorphic zone adjoining the atmosphere is called the crust of weathering while the lower portion is called the belt of cementation

The lithosphere can be observed only to a small depth for the deepest boreholes hardly reach 6 5 kilometres and it is only in certain folded areas of the Earth that the rocks that formerly occurred at a depth of 15 16 kilometres are exposed on the surface by mountain making disturbances

The chemical composition of the Earth's crust has been computed on the basis of analyses of minerals and rocks. According to the Soviet mineralogist and geochemist A. Vinogradov, the lithosphere consists of the following elements (in weight percentages): O—46.8, Si—26.00, Al—7.45, Fe—4.20, Ca—3.25, Mg—2.35, Na—2.40, K—2.35, H—1.00.

As the above figures show, nine elements contribute more than 98 per cent of the weight of the Earth's crust with oxygen making up nearly half of it within limits of the depth indicated above, and silicon accounting for a little over a quarter of the weight. These two elements thus account for more than three quarters of the weight of the Earth's crust. Aluminium, iron, alkaline and alkaline-earth metals and hydrogen account for 23 per cent and the other elements for 1.2 per cent of the weight of the Earth's crust. The content of titanium, carbon and phosphorus is measured in tenths of one per cent, the content of manganese, sulphur, barium, chlorine, chromium, fluorine, zirconium, nickel, strontium, vanadium, copper in hundredths of one per cent, and the content of tungsten, lithium, hafnium, lead and cobalt in thousandths of one per cent. The other elements are represented in still smaller quantities (radium, for example).

The elements which occur in the Earth's crust in minute

Crystalline Structure of Minerals

The majority of the known minerals are in a crystalline state and only a small number is in an amorphous state The difference between the crystalline and amorphous state is that when elements are in a crystalline state the molecules atoms or ions of each are arranged in a definite order and form a spatial lattice (Fig 5) while in the second case there is no regular arrangement of particles The difference in the internal structure of crystalline and amorphous bodies accounts for the difference in their physical properties (thermoconductivity, electric conductivity magnetisation hardness and so on) In a spatial lattice the particles are equidistant from each other in any parallel direction, but the distance between them can vary in non parallel directions Accordingly the properties of crystalline bodies defined by the interrelation between the constituent particles are constant in parallel directions and may change in other directions This is due to the structure of the spatial lattice The physical properties of amorphous bodies are equal in all directions and are defined only by the chemical composition of the substance That is why in contrast to crystalline bodies which are anisotropic such bodies are called isotropic

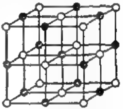

Fig 5 Spatial lattice of rock salt

Minerals which are in a crystalline state are generally found in grains of irregular shape and seldom in the form of rectilinear polyhedrons—crystals (Fig 6)

Each mineral has its own more or less constant crystal form which depends on the internal structure of the substance—its spatial lattice Each crystal is bounded by planes called crystal faces the lines of the face intersection are called crystal edges the points where the edges intersect are called apexes (Fig 7)

Under the influence of the environment the shape of the crystal faces their size and occasionally even their

Fig. 6. Quartz crystals

Crystals are symmetrical, that is to say their individual elements (faces edges and apexes) or combinations of elements are regularly repeated, this can be noted when a crystal is dissected by a plane when it rotates about a certain axis or when the arrangement of its separate elements is compared in relation to a definite point inside it. These planes axes and points are the elements of crystal symmetry and are called respectively the plane of symmetry the axis of symmetry and the centre of symmetry.

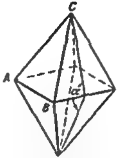

Fig 7 Elements of a crystal

ABC—face AB—edge α—dihedral angle C—apex

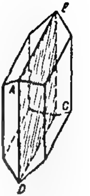

Fig 8 Plane of symmetry *ABCD*

An imaginary plane dividing the crystal into two equal or mirror image parts is called *the plane of symmetry* (Fig 8) it is designated by the letter P

An *axis of symmetry* is an imaginary axis which allows individual elements of a crystal to repeat themselves when the crystal makes a complete revolution of 360 it is designated by the letter L. During a complete revolution this repetition of the same position can be observed 2 3 4 and 6 times. Accordingly, the axes will be called axes of

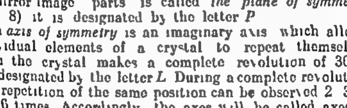

Fig 9 Axes of symmetry

symmetry of the second third fourth and sixth order and designated by the letters L_2, L_3, L_4 and L_6 (Fig. 9).

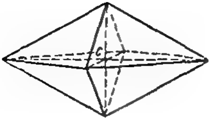

Fig. 10 Centre of symmetry

The point inside the crystal at which all straight lines connecting the respective points of the crystal surface intersect and reciprocally divide into two parts is called *the centre of symmetry*. It is designated by the letter C. A crystal can have only one centre of symmetry (Fig. 10).

A crystal that has the form of a cube belongs to the group of figures with the greatest degree of symmetry. It has three axes of symmetry of the fourth order ($3L_4$) passing through the middle of the cube faces, four axes of symmetry of the third order ($4L_3$) passing through the apexes of the trihedral angles and six axes of symmetry of the second order ($6L_2$) passing through the middle of the edges (Fig. 11). More

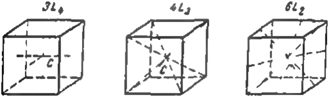

Fig. 11 Axes of symmetry of a cube

over nine planes of symmetry ($9P$) can be drawn in the cube (Fig. 12). The centre of symmetry in the cube lies at the point where the axes of symmetry intersect.

On the basis of the combination of the elements of symmetry and other features, crystals are classified into the following seven systems: cubic, hexagonal, tetragonal, trigonal, orthorhombic, monoclinic and triclinic.

The largest number of elements of symmetry is observed in crystals of the highest *cubic* system. Their feature is

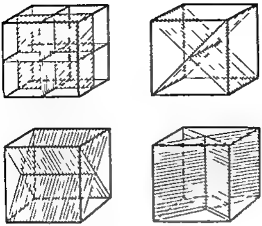

Fig 12 Planes of symmetry of a cube

that they have more than one axis of symmetry above the second order

Crystals with only one axis of symmetry above the second order belong to the middle systems Depending on the axis order the following three systems are distinguished among them

hexagonal which consists of crystals with one axis of symmetry of the sixth order

tetragonal which consists of crystals with one axis of symmetry of the fourth order and

trigonal which consists of crystals with one axis of symmetry of the third order

Crystals with no axes of symmetry or only axes of the second order belong to the lowest systems The following systems are distinguished among them

orthorhombic which consists of crystals that have several axes of symmetry of the second order or several planes of symmetry

monoclinic which consists of crystals that have either one axis of symmetry of the second order or one plane of symmetry

triclinic which consists of the most asymmetric crystals or crystals devoid of elements of symmetry or crystals that only have a centre of symmetry

Above we have indicated the minimum number of elements of symmetry necessary to class crystals as belonging to any of the listed systems except the triclinic. Moreover, crystals of the highest and middle systems may have axes of the second order, planes and a centre of symmetry. Crystals of the orthorhombic and monoclinic systems may have axes of the second order and planes as well as a centre of symmetry.

As we have already noted, minerals either form granular concentrations or are occasionally found in the shape of separate crystals or clusters of crystals. The nature of these mineral concentrations and clusters depends principally on the conditions in which the crystals were formed.

Granular clusters are concentrations of mineral grains of different irregular shape that depends on the spatial outline in which the mineral had crystallised.

Druses are clusters of crystals incrusted at one end to some surface.

Concretions are mineral accumulations that grow from some nucleus to the periphery and form radially fibrous or concentrically composed clusters. Oölites are also concretions. They are mineral accumulations of spherical concentric conchoidal or radially fibrous bodies that form when a substance settles around some minute particles.

Secretions are formed when a mineral substance fills cavities in rocks. In contrast to concretions, the deposition of substance proceeds from the periphery to the nucleus. Secretions of up to ten millimetres in diameter are called *amygdales*, larger secretions are called *geodes*.

Sinter forms of mineral clusters originate during the slow coating of some surface by a mineral substance. The main role in this process is played by colloid solutions. Typical reniform, botryoidal clusters or clusters in the shape of icicles (stalactites and stalagmites) are formed.

Physical Properties of Minerals

There are different methods for identifying minerals: they are based on a determination of the habits of crystals, on a study of their optical and chemical proper

ties chemical composition and so forth Science has reached a level where minerals can be identified through X ray diffraction spectrographic and thermal analyses and other methods of precise mineralogical study For the sake of accuracy minerals are identified by several methods simultaneously

In order to conduct geological explorations in the field it is necessary to be able to identify the principal minerals on sight Attention must be paid to the following basic properties of minerals colour of a mineral in fragment and in powder the lustre the transparency, the fracture the *cleavage, the hardness and the specific gravity* These properties are closely associated with the internal structure of minerals with the texture of their crystalline lattice In this connection each mineral which is in a crystalline state has a definite number of properties that change regularly with the anisotropy inherent in minerals

Colour The colour of a mineral in fragment and in powder form may be different The *colour of a mineral in fragment* depends on the basic chemical composition of the mineral concerned on the arrangement of the ions and atoms in the crystalline lattice and on insignificant chemical and mechanical impurities which can change the colour but do not influence other properties On account of this we find different minerals having the same colour (for example, rose coloured gypsum and rose coloured halite) or one and the same mineral having different colours (for instance flint may be white brownish grey brown, red black or some other colour)

When a mineral is described, its colour should be stated as accurately and clearly as possible by comparing it with the colour of well known objects, for instance, milk white lemon yellow and so on

In the case of some minerals the colour of the *powder* or *streak* often differs from that of the fragment For instance pyrite fragments are golden-yellow while the powder of this mineral is greenish black To determine the colour of the powder of a mineral a streak of this powder is usually made on the rough surface of an unglazed porcelain plate This makes it possible to differentiate between for example two minerals whose outward appearance is

very similar say hematite and magnetite the power of the former leaves a cherry red streak and of the latter a black streak

Lustre For their lustre all minerals are divided into two groups The first group consists of minerals with a metallic lustre in a reflected light the surface of these minerals is reminiscent of a metal surface Native metals and most sulphides have a metallic lustre A deep metallic lustre occasionally makes it difficult to determine the colour of a mineral This group also includes minerals graphite for example which have a *submetallic* lustre that resembles the lustre of tarnished metal

The second bigger group consists of minerals with *non metallic lustre* In this group the lustre of minerals is subdivided as follows adamantine—this is the most intensive lustre and is typical for a small number of transparent or translucent minerals (diamond sphalerite and others) vitreous—reminiscent of a glass surface—is a feature of most transparent and translucent minerals (rock crystal calcite halite and so forth) greasy which gives the impression that the surface of a mineral is coated by a thin film of grease—this is a feature of quartz at fracture native sulphur nephelenite and other minerals mother of pearl (mica talc) silky—this is the lustre of minerals with a fibrous structure (fibrous gypsum asbestos) Finally there are minerals whose surface has no lustre at all In such cases it is said that minerals have a *dull* lustre

Transparency *The transparency of a mineral depends* on its ability to transmit rays of light Accordingly the following varieties of minerals can be distinguished

non transparent minerals i e minerals that do not transmit light even through very thin sheets These minerals have a metallic lustre and leave a black or dark streak (native metals many sulphides ferric oxides and other minerals)

transparent minerals that admit the passage of light like ordinary glass (for example rock crystal and Iceland spar)

translucent minerals that admit the passage of light like frosted glass (for example chalcedony gypsum and occasionally opal)

minerals that are non transparent as fragments but admit the passage of light along a thin edge (for example feldspars many carbonates and silicon)

Fracture When various minerals are broken we get fractures of various shape Often these fractures have the shape of a smooth concave or convex surface with concentrically arranged riblets—waves resembling the structure of a shell Such fractures are called *conchoidal*

In other cases the surface of the fracture is covered with small splinters This is called a *splintery* fracture and is a feature of minerals with a fibrous long columnar structure (for instance amphibole) Some minerals, for example kaolinite have an earthy fracture resembling the rough surface of clay In the case of other minerals an uneven surface is formed when they break and this is called an *uneven* fracture

Cleavage which is the result of the tendency of minerals to split along parallel planes (planes of cleavage) is a form of fracture This property is due to the structure of a mineral s crystalline lattice and manifests itself in definite crystallographic planes in which the adhesive force between separate atoms falls to a minimum

Depending on how clearly the cleavage is defined the following degrees of cleavage are distinguished

eminent cleavage when a mineral easily splinters into sheets with smooth shining parallel surfaces This is a feature of mica (Fig 13)

perfect cleavage, when a mineral that is struck breaks easily along definite planes (for example calcite and halite)

medium cleavage when a mineral that is struck breaks equally often along cleavage planes as uneven fractures are formed in it (feldspars)

imperfect cleavage is ascertained with difficulty in the form of small facets against the background of an uneven fracture (apatite native sulphur)

highly imperfect cleavage means that there is practically no cleavage It is never possible to find even planes on the fracture of minerals with a highly imperfect cleavage (for instance in quartz)

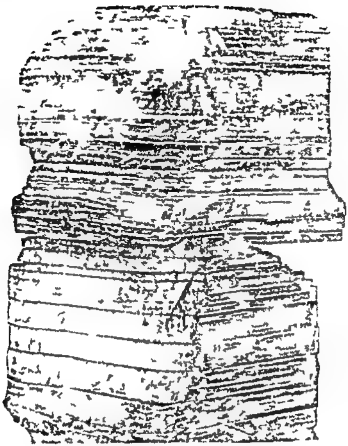

Fig 13 Mica Eminent cleavage in one direction

Besides determining the degree of cleavage it is necessary to mark out the planes in which it is expressed Some minerals mica for example have a cleavage in only one plane Other minerals are cleaved in two planes and the degree of this cleavage can be different As an example let us take feldspar It has a perfect cleavage in one

plane and a medium cleavage in the other. There are minerals with a three-plane cleavage: halite and calcite, for example (Fig. 14).

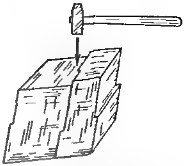

Fig. 14. Calcite. Perfect cleavage in three directions along a rhombohedron

Crystal faces can be mistaken for planes of cleavage and to distinguish between them it should be remembered that as a rule lustre is greater along the planes of cleavage than along the crystal faces.

Hardness. An important property that helps us to identify minerals is their hardness, i.e., their resistance to mechanical action.

Ten minerals have been selected as standards of hardness and arranged into a scale in the order of hardness relative of which the hardness of all other minerals is determined (Table 2).

Table 2

Hardness Scale

Mineral	*Hardness*	*Mineral*	*Hardness*
Talc	1	Orthoclase	6
Gypsum	2	Quartz	7
Calcite	3	Topaz	8
Fluorite	4	Corundum	[illegible]
Apatite	5	Diamond	10

Each mineral from the hardness scale can scratch the softer mineral preceding it and can be scratched by the harder mineral below it.

To determine the hardness of a mineral an even facet is chosen on its surface and run over with the sharp edge of

a mineral from the hardness scale If a scratch is made on the investigated mineral it means that it is softer than the mineral standard if no scratch is produced it means the investigated mineral is harder than the mineral standard This test should be continued until the investigated mineral fits into an interval between two minerals in the hardness

Fig 1 Double refraction in a piece of Iceland spar

scale i e until its hardness is determined as being intermediate between them or as equal to the hardness of one of them If the hardness of a fine grained mineral is tested it is more convenient to scratch the mineral from the hardness scale with the grains of the mineral being tested

The hardness of a mineral can also be determined with the aid of a number of objects which are always on hand for example the hardness of the lead of a soft pencil is taken as 1 the hardness of halite or salt is taken as 2 of a finger nail as from 2 5 to 3 of a nail or wire as 4 of glass as 5

of a steel blade or needle as about 6, of widespread minerals such as quartz and silicon as 7 Minerals of a greater hardness occur very rarely

Specific Gravity It is only in a laboratory that specific gravity can be accurately determined But in order to identify minerals it is important to be able by simply weighing them in your hand to determine if they belong to the group of light minerals with a specific gravity of 2 5 to the group of middle minerals with a specific gravity of 3 5 to 4, or to the group of heavy minerals with a specific gravity of over 4 5 With some practice one soon becomes able to determine specific gravity with sufficient accuracy

When a mineral is studied attention must be paid to all the physical properties enumerated above because only when all these properties are determined is it possible to identify the mineral correctly

Some minerals have properties that are not found in any other mineral For instance carbonates more or less freely react with hydrochloric acid and liberate bubbles or carbonic acid gas this is called the boiling up of a mineral Double refraction is a feature of pure calcite (Iceland spar) (Fig 15) Magnetite is strongly magnetised and being brought to the magnetic needle deflects it Halogen minerals (halite) freely dissolve in water and have a characteristic taste

Classification of Minerals

Approximately 3 000 different minerals are known at present but only a small number (about 50) is widespread in the Earth s crust the rest occur rarely

Feldspars are the most widespread group of minerals in the lithosphere adding up to nearly 60 per cent then follows quartz—12 6 per cent mica—3 6 per cent ferruginous magnesia silicates—16 8 per cent lime feldspar (calcite)—1 5 per cent dolomite—0 1 per cent various clay minerals—about 1 per cent All the other minerals hardly account for 1 per cent of the Earth s mineral mass Minerals that are important constituents of ordinary rocks are called rock forming minerals

All known minerals according to their chemical composition and crystalline texture are divided into several classes of which the most important are
1 native elements
2 sulphides
3 halides
4 oxides and hydroxides
5 carbonates
6 sulphates
7 phosphates
8 silicates
The properties of the principal rock forming minerals and of essential minerals are described below

Native Elements

Native elements are seldom found in nature they are not rock forming The origin of native elements may be associated with magma solidification with secondary chemical reactions or with the action of high temperatures and pressures

Graphite [C] is rarely found in the form of small tabular crystals of the hexagonal system It occurs most often as a compact or scaly mass It has a dark colour—from steel grey to black The streak is dark grey to black and shiny The lustre is submetallic The cleavage is perfect in one plane the flakes are thick and easily friable in thin flakes graphite is flexible Hardness—1 Specific gravity—2 09 2 23 It is greasy to the touch soils hands and leaves a streak on paper

The origin of graphite is linked up with magmatic and metamorphic processes It is used principally in the manufacture of pencils and fire proof crockery and as a lubricant for friction parts when on account of high temperatures oil cannot be used

Diamonds are a crystalline variety of pure carbon They are extremely transparent very hard (hardness—10) and have a brilliant lustre They occur very rarely and are used as an abrasive in engineering and also as jewelry Diamonds are one of the most precious minerals The Soviet Union has deposits of diamonds in the Yakut Autonomous Republic

Sulphur [S] is occasionally found in the form of crystals of the orthorhombic system well faced and forming druses in sinter forms but more often as an earthy powder-like mass It is yellow of various shades up to green brown Its lustre along a fracture is greasy, dull Sulphur is translucent The cleavage is imperfect The fracture is conchoidal and earthy Hardness—1-2 Specific gravity—2 05 2 08 Sulphur electrifies during friction, is inflammable and burns with a blue flame liberating a fetid sulphurous gas

Native sulphur is formed during the decomposition of sulphate and sulphurous minerals and during the sublimation of vapours and gases released by volcanic vents Sulphur deposits are known in some regions of volcanic activity For instance there are large quantities of sulphur in Italy where it is one of the products of the eruption of volcanoes of the Vesuvius and Etna group In the U S S R there are deposits of sedimentary sulphur in Central Asia and in the Volga Area

Gold [Au] is a precious metal and is found in the form of crystals grains lamellae and nuggets It crystallises in the cubic system Its colour is yellow and it has a high specific gravity (15 6 19 3) It is extremely malleable Hardness—2 5-3

In a dispersed state gold occurs in rocks in rivers and oceans and even in the tissue and blood of living organisms In nature we find mainly native gold There are primary deposits (inclusions in ore bodies) and placers (destroyed and redeposited primary deposits) In ores and in placers gold is found in the form of tiny grains but quite often nuggets weighing dozens of kilograms are encountered Native gold occurs in various shape lamellae grains rods and so forth The surface of particles of native gold is covered occasionally with films of other substances e g with hydrous oxide of iron

Platinum [Pt] like gold is a precious metal It is found mainly in a virgin state in the form of grains and flakes of different size and seldom in the form of large nuggets It is steel grey Hardness—4 5 Specific gravity—14 19 Like gold it comes from primary and placer deposits

Platinum is infusible chemically stable and conducts electricity and is therefore widely used in the chemical and

electrical engineering industries The biggest platinum de posits are in the U S S R (the Urals) Canada, South Africa and Colombia

Sulphides

For the number of minerals (more than 250) this class is second after silicates But for their occurrence in the Earth s crust minerals of the sulphide class like native miner als occupy one of the last places and are not rock forming However some are of great practical importance Their chem ical composition is simple and is a combination of var ious elements with sulphur The origin of sulphides is linked up principally with precipitation from hot aqueous solutions and in a lesser degree with magma solidifica tion and cold solutions The majority of the minerals of this class have a metallic lustre a relatively low hardness and as a rule a high specific gravity

Pyrite [FeS_2] is one of the most widespread minerals of this class It is often found as well defined crystals of the cubic system particularly as cubes on the faces of which a fine parallel striation is visible it is also found as granular or compact clusters and round concretions with a radiated structure It is light or golden yellow The streak is black or greenish black The lustre is sharply metallic which sometimes makes it difficult to determine its colour Pyrite is not transparent The cleavage is imperfect The fracture is uneven or conchoidal The fracture of clusters is granular Hardness—6 6 5 Specific gravity—4 9 5 2

Pyrite often forms extensive accumulations which are developed with a view to producing sulphuric acid

Chalcopyrite [$CuFeS_2$] crystallises in the tetragonal system It frequently occurs in the form of compact masses crystals are rare Its colour in contrast to that of pyrite is lighter—a brass yellow It is not as hard (3 4) as pyrite Its specific gravity is 4 1 4 3 It is a widespread copper ore

Galena [PbS] crystallises in the cubic system It occurs in the form of granular less often compact mass The crystals usually have the form of cubes seldom that of octahedrons The colour is lead-grey Its streak is a shiny

greyish black It is not transparent Its lustre is metallic The cleavage is perfect in three planes parallel to the cube faces Hardness—2 3 Specific gravity—7 4 7 6

Galena is an important lead ore

Sphalerite [ZnS] crystallises in the cubic system It occurs in the form of fine grained or nodular masses and crystals of regular tetrahedral shape The cleavage is emi nent The colour is inconstant brown yellow or reddish The streak colour is yellow or brown The lustre is metallic and brilliant Hardness—3-4 Specific gravity—3 5 4 2

Sphalerite is an important zinc ore

Halides

This class embraces a large number of minerals representing salts of haloid acids precipitated from aqueous solutions Only a few minerals of this class chiefly chlo rides are rock forming

Halite [NaCl] which crystallises in the cubic system is the most widespread mineral of this class It usually occurs in the form of crystalline clusters and seldom as cubic crystals Pure halite is colourless or white Varie ties of halite of different light colours (red, yellow bluish, grey) are frequently encountered the colour is due to impurities The lustre is vitreous Halite is transparent or translucent Its cleavage is perfect in three planes parallel to the cube faces Hardness—2 Specific gravity—2 1 2 2 It dissolves rapidly in water and has a typical salty taste Beds and nests of halite occur in strata with other sedimentary rocks Ocean water contains three per cent dissolved halite Halite sometimes settles on the bottom of salt lakes and bays where it is known as solar salt Ground water is often saturated with halite and occasionally this results in salt springs The water in these springs evaporates in summer and freezes out in winter and is the source of what is known as evaporation salt

Halite is used in food (as common salt) and also in the chemical industry The best known rock salt deposits are in the Urals the Donets Basin near Iletskaya Zashchita and on the Taimyr Peninsula Solar salt is obtained from lakes Elton and Baskunchak Salt springs are encountered

in Slavyansk Bakhmut District near the towns of Balakhna and Usolye and in other places

Sylvite [KCl] forms in the same conditions as halite but occurs less frequently it is sometimes found in granular intergrowths with halite Its physical properties are similar to those of halite The distinguishing features of sylvite are its burning salty taste and bright red or dark blue colour

Fluorite [CaF_2] crystallises in the cubic system forms granular clusters and is found as separate, well defined crystals usually as cubes and less often as octahedrons

It occurs in a variety of colours colourless yellow green blue violet and pink One and the same crystal is frequently multi coloured This mineral has a vitreous lustre is translucent and the pure varieties are transparent (optical fluorite) The cleavage is perfect in four planes parallel to the octahedron faces When fluorite is heated it fluoresces in darkness Hardness—4 Specific gravity—3 1 3 2 Under the action of sulphuric acid fluorite dissolves liberating fluoric acid [HF] which intensively corrodes glass

Fluorite owes its origin chiefly to hot solutions occasionally it occurs in sediments precipitated from cold waters It is very important in metallurgy

Oxides and Hydroxides

In this class the minerals are combinations of various elements with oxygen and with the OH hydroxyl group It is one of the most numerous classes of minerals and for its weight accounts for nearly 17 per cent of the lithosphere

Quartz [SiO_2] is one of the most common minerals of the Earth s crust It is an important constituent of rocks formed deep in the Earth and on its surface i e it takes part in the formation of magmatic sedimentary and metamorphic rocks It occurs in the form of granular clusters and irregular grains occasionally it is formed in veins and vugs as well cut crystals and clusters of crystals Quartz crystals have the shape of a hexahedral prism terminating at one or both ends in rhombohedrons The faces of the prism are often covered with a fine transversal striation Transparent quartz crystals are called rock crystals Although

quartz is colourless or white when pure it is often tinted For example there is a smoky rock crystal with a greyish tint and an amethyst rock crystal with a violet tint Black quartz is called morion The faces of the crystal have a vitreous lustre, and the fracture is greasy Quartz has a highly imperfect cleavage The fracture is conchoidal or uneven Quartz has a hardness of 7 and a low specific gravity of 2 5 2 8 It dissolves only in hydrofluoric acid

It forms during the solidification of magma and is segregated from hot solutions and also during the metamorphisation of rock High temperature quartz crystallises in the hexagonal system and low-temperature quartz in the trigonal system A cryptocrystalline variety of quartz (chalcedony) and not quartz proper forms on the Earth s surface during the dehydration and crystallisation of silica gel

Chalcedony [SiO_2] is a cryptocrystalline variety of quartz occurring in the form of compact masses sinter and reniform clusters or nodules Chalcedony polluted with impurities such as clay particles is called silicon It occurs in a variety of colours Grey is a frequent colour but there is also brown, nearly white yellow dark red and even black silicon A variety of chalcedony with bright colours arranged in concentric circles is called agate It has a weak greasy dull lustre and is transparent at the edges The fracture is conchoidal Hardness—6 7 Specific gravity—2 4 2 5

Opal [$SiO_2 \cdot nH_2O$] is an amorphous mineral It has a water content of 1 5 per cent which occasionally rises to 34 per cent It is usually found in the form of compact sinter masses It is colourless but impurities give it different colours Precious opal is milk white with a beautiful play of colours Opal is semitransparent or translucent along the edges It has a weak vitreous or greasy dull lustre The fracture is conchoidal or uneven Hardness—5 5 5 occasionally 6 Specific gravity—2 2-2 5

Opal forms chiefly on the Earth s surface as a result of the weathering of silicates and also of precipitation in water basins Some protozoans and lower plants have an opal skeleton It is also known that opal segregates from hot solutions Quartz is used in optics metallurgy and the glass industry Quartz chalcedony and opal are also used in the manufacture of objects of art

Hematite [Fe_2O_3] crystallises in the trigonal system It is usually found in the form of compact microcrystalline scaly or lamelliform concentrations (iron glance specular iron), in the form of nodules of radiated or conchoidal structure and cryptocrystalline masses In the latter case it is called red iron ore Quite frequently hematite is found

Fig 16 Magnetite crystals as they occur in nature

in the form of crystals of rhombohedral and lamellar shape The colour of crystalline varieties of hematite is iron black and of den e cryptocrystalline varieties—red It has a blood red streak The lustre varies from metallic to dull Hematite is not transparent even in fine lamellae Hardness—5 5-6 the cryptocrystalline masses are softer The fracture is conchoidal It has a high specific gravity (5 3) which is typical for ferruginous minerals Hematite egregates chiefly from hot solutions and during metamorphism It is an important iron ore

Magnetite [$FeO \cdot Fe_2O_3$] crystallises in the cubic system It is found in the form of compact granular clusters occasionally as octahedron crystals impregnated in rocks (Fig 16)

The outward appearance and physical properties of magnetite resemble those of the crystalline variety of hematite but the former is distinguished from the latter by its black streak and magnetisation (it attracts needles and nails and deflects the magnetic needle)

Magnetite forms during the solidification of magma and segregates from hot solutions and in the course of metamorphism It is a very important iron ore There are rich deposits of magnetic iron ore in the Urals (mounts Magnitnaya, Blagodat Vysokaya and others)

Limonite [$Fe_2O_3 \cdot nH_2O$] is a hydrous oxide of iron The quantity of water in this mineral varies this results in a change of colour as well The colour of loose varieties is a light yellow while that of compact varieties is brown red brown or brown black The streak is yellow-brown or brown Hardness—1 5 Specific gravity—3 3 4 Brown iron ore is sometimes found in the form of oolites and has various local names bean ore bog ore, meadow ore and so on An interstratification of loose and compact varieties can frequently be seen in a specimen

Limonite is a mineral of surface origin and forms during the weathering of all other ferruginous minerals thanks to the activity of microorganisms it also precipitates in surface basins

Limonite is an iron ore

Corundum [Al_2O_3] crystallises in the trigonal system and forms columnar pyramidal and lamellar crystals It is dark blue red, green or brown and occasionally separate parts of the same crystal have a different colour Hardness—9 Specific gravity—3 9 4 Corundum does not dissolve in acids It is a mineral of magmatic origin There are deposits of corundum in the Urals Kazakhstan and Yakutia

It is of great importance in engineering as an abrasive and cutting material A red transparent variety of corundum is called a *ruby* and a dark blue variety is called a *sapphire* Rubies and sapphires are gems There is now an industry manufacturing artificial rubies They are of great importance in engineering particularly in watchmaking thanks to their exceptional hardness

Carbonates

The minerals of this class are carbonic acid salts. Some of them are rock-forming minerals of sedimentary and metamorphic rocks. A feature of carbonates is that they react with hydrochloric acid (HCl). This reaction produces carbon dioxide (CO_2) bubbles which give the impression that the mineral "boils". The reaction proceeds as follows:

$$CaCO_3 + 2HCl = CaCl_2 + H_2CO_3$$
$$H_2CO_3 = H_2O + CO_2$$

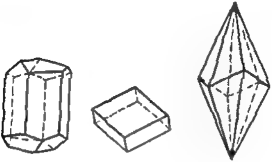

Fig. 17. Calcite crystals

Outwardly similar carbonates can be distinguished by the intensity of this reaction.

Calcite ($CaCO_3$) is the most widespread mineral of the carbonate class. It crystallises in the trigonal system and is found as druses or separate crystals (Fig. 17); it often forms sinters in the shape of stalactites and stalagmites. Calcite is colourless or white; impurities may give it various colours. It has a vitreous and occasionally a mother-of-pearl lustre. It is transparent or translucent. The cleavage is perfect in three planes parallel with the faces of the rhombohedron. Hardness—3. Specific gravity—2.6-2.8. Calcite reacts violently with hydrochloric acid.

The colourless transparent variety of calcite is called Iceland spar; it has the property of double refraction (Fig. 15) and is used in optical instruments.

When calcite is heated it liberates carbon dioxide cal cium oxide [CaO] known as burnt lime remains When wat er is added burnt lime turns into slaked lime [$Ca(OH)_2$] Slaked lime adsorbs carbon dioxide from the air and con solidates

Calcite precipitates from surface waters from hot solutions, and is also formed in the course of metamorphism Widely occurring rocks, such as limestones chalks and marbles consist of calcite There are commercial deposits of chalk in the vicinity of Belgorod and in the Donbas Marble is quarried in the Caucasus the Urals the Carpa thians and Karelia

In the Urals Yakutia, the Crimea and the Caucasus there are deposits of well defined calcite crystals Ideally transparent calcite crystals were first described in Ice land, hence their name—Iceland spar

Aragonite [$CaCO_3$] as distinct from calcite crystal lises in the orthorhombic system It often forms dense sinter clusters and less often oolite concentrations and acicular crystals It is distinguished from calcite by a somewhat higher hardness (3 5 4) an indistinct cleavage and crystal shape It precipitates from hot water springs the shells of mollusks are formed from it

Magnesite [$MgCO_3$] is a rarer mineral than calcite or aragonite Compared with calcite its hardness and specif ic gravity are somewhat higher It is used in the manu facture of fire proof bricks and cement There are large deposits of magnesite in the Urals

Dolomite [$MgCO_3\ CaCO_3$] is a widespread mineral of complex composition It is colourless or white but often due to accidental impurities it is greyish or dark It often forms beds of considerable thickness Hardness—3 5-4 Specific gravity—1 8 2 9 Only powdered dolomite reacts with hydrochloric acid

Siderite [$FeCO_3$] is a brown yellow or brown mineral with a vitreous or dull lustre It has a hardness of 3 5-4 5 and a specific gravity of 3 7 3 9 When it is free of impuri ties it is an excellent iron ore

Malachite [$CuCO_3\ Cu(OH)_2$] is a widely occurring mineral with a 57 4 per cent copper content It crystallises in the monoclinic system but crystals occur rarely It is

usually found as thin radial growths compact or sinter (reni form) concentrations with a convergence zonal structure and a radial fibrous texture of separate layers and zones It is often found in the form of selvedges incrustations and earthy clusters Its colour varies from blue-green to dark green It has a silky lustre Hardness—3 5-4 0 Specific gravity—3 9-4 1

Malachite is a secondary mineral of the oxidation zone of sulphide copper deposits which occur in limestones and other carbonate rocks

It is a valuable commercial copper ore but as a rule the deposits are not large Beautifully patterned malachite is a valuable industrial stone for decorative objects

Azurite [$2CuCO_3$ $Cu(OH)_2$] crystallises in the monoclinic system It is found in crystals grained and earthy clus ters incrustations fine cavity fillings and so forth The colour of azurite crystals is a deep dark blue Earthy clus ters called copper blue have a bright or light blue col our Crystalline azurite has a vitreous and earthy dull lustre Hardness—3 5 4 Specific gravity—3 7 3 9 The cleav age is medium in one plane Azurite dissociates freely when it is oxidised and liberates carbonic acid gas

It is a typical mineral of the zone of oxidation of copper deposits and forms during the weathering of chalcopyrite bornite grey copper ore chalcocite covellite and other copper sulphides Malachite is the most usual companion of azurite Azurite is used in copper smelting and in the manu facture of blue paint It does not form large accumulations

Sulphates

The majority of sulphates are rock forming minerals of sedimentary rocks Their formation is the result of the pre cipitation of the salts of sulphuric acid from surface wat er or they are products of the oxidation of sulphides

Gypsum [$CaSO_4$ $2H_2O$] is one of the principal rock form ing minerals of sedimentary rocks It is frequently found in well defined crystals of the monoclinic system Some times it occurs in columnar and scaly form not infrequently as twin crystals (Fig 18) but most often as compact masses The cleavage is perfect Hardness—2 it can be scratched

easily with a finger nail Specific gravity—2 3 Pure varieties of gypsum are colourless sometimes gypsum is white grey blue or pink It is transparent or translucent It has a vitreous and mother of pearl lustre Gypsum crystals with a fine fibrous structure are called *selenite*

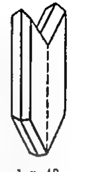

Fig 18 Swallow tail gypsum twin

At a temperature above 100°C gypsum loses a part of its water and turns into semihydrate [$CaSO_4 \frac{1}{2}H_2O$] The latter is ground into flour which after the addition of water becomes a paste and quickly consolidates, liberating heat as it does so Thanks to this gypsum is used in medicine for plaster of Paris bandages in the manufacture of cement in architecture, sculpture and other fields It is also of great importance in the chemical industry Gypsum deposits often adjoin deposits of rock salt

Anhydrite [$CaSO_4$] crystallises in the orthorhombic system It is usually found in the form of compact fine grained clusters Though it is generally white it sometimes has a faint bluish or greyish tint It has a vitreous and mother of pearl lustre Anhydrite is transparent but more often it is translucent The cleavage is perfect and medium in two planes at an angle of 90° Hardness—3 3 5 Specific gravity—2 8 3

Phosphates

Apatite [$Ca_5(PO_4)(CaF)(CaCl_2)$] is the most widespread mineral of this class It crystallises in the hexagonal system is usually found in the form of fine grained clusters seldom as separate crystals in the shape of hexahedral prisms Its colour varies from white to brown while large crystals are frequently pale green or greenish blue yellowish violet red or brown It has a vitreous lustre on its faces and a greasy lustre on fractures The cleavage is imperfect Hardness—5 Specific gravity—3 2

It is very important as a raw material for fertilisation It is found chiefly in sedimentary rocks but there also are apatites of magmatic and metamorphic origin

structure is associated with lamellar crystals an eminent cleavage in one plane and a low hardness All laminated silicates crystallise in the monoclinic system From the chemical point of view like amphiboles they are characterised by the presence of the OH hydroxyl group

First and foremost among laminated silicates there are the minerals of the *mica* group which are typical of magmatic and metamorphic rocks Mica crystals are tabular Mica is easily split along its cleavage into extremely thin elastic sheets (Fig 13)

Muscovite [$KAl_2(OH)_2(AlSi_3O_{10})$] is usually colourless and often has a green or pale yellow tint It has a vitreous mother of pearl lustre It is transparent thanks to which it was formerly used instead of glass in windows The cleavage is eminent in one direction the sheets are elastic Hardness—2 3 Specific gravity—2 7 3 Muscovite is chiefly used in the electrical engineering industry as an insulating material Commercial deposits of muscovite are linked up with pegmatites

Western Europe used to import this mineral from Muscovy where the deposits were worked as far back as in the Middle Ages Hence the name

Biotite [$K(Mg\ Fe)_3(OH)_2(AlSi_3O_{10})$] differs from muscovite by its brown or black colour weaker transparency (it is only translucent) and by a somewhat higher specific gravity (3 3 1) When black mica is weathered it acquires a bronze tint

Talc [$Mg_3(OH)_2(Si_4O_{10})$] is found in compact foliated or scale clusters separate crystals are very rare It is white pale green bluish green or silvery It often has a mother of pearl lustre which turns dull in compact clusters The cleavage is eminent in one plane The lamellae split along the cleavage are flexible and non resilient Talc is greasy to the touch Hardness—1 Specific gravity—2 7 2 8

Talc forms as a result of the metamorphism of magnesium rich silicates particularly of olivine pyroxenes and amphiboles Thanks to its softness and eminent cleavage it is used for lubrication Soapstone (a massive variety of talc) is used as a refractory material

Serpentine [$Mg_6(OH)_8(Si_4O_{10})$] is commonly found in compact masses and occasionally in the form of sinter clus

ters only one variety of serpentine—antigorite—is known to have crystals The colour varies from whitish green to black green The colouring is frequently arranged in irregular spots hence the name (from the Latin—*serpens*) It has a vitreous greasy lustre Cleavage is only observed in *antigorite* *Hardness*—2 5 4 *Specific gravity*—2 5 2 6 Serpentine forms in the course of the metamorphism of basic rocks

A thin fibrous variety of serpentine is called *chrysotile-asbestos* It is white and sometimes green yellow It has a silky lustre Hardness—2 3 This mineral splits into snow white thin flexible fibres and is usually associated with fissures, standing out in the form of veins against a background of compact serpentine

Kaolinite $[Al_4(OH)_8\ (Si_4O_{10})]$ is found in compact and earthy clusters The crystals are very small and can be studied only under a microscope It is white and in the smallest crystals it is colourless It has a dull lustre The fracture is earthy Hardness—1 Specific gravity—2 6 It is greasy to the touch In a dry state it easily absorbs moisture and becomes plastic

In contrast to silicates (described above) kaolinite forms principally on the surface of the Earth during the weathering of alumosilicates chiefly micas and feldspars (see below)

Several minerals of similar composition and representing mixtures of two compounds—$Mg_6(OH)_8(Si_4O_{11})$ and $Mg_4Al_2(OH)_8\ (Al_2Si\ O_{10})$ in which Mg^{2+} replaces Fe^{2+}—are part of the *chlorite* group Chlorites are found in the form of compact or scaly dark green clusters They have a mother of pearl and vitreous lustre Hardness—2 2 5 The cleavage is eminent in one plane Like micas chlorites split into scales but they are not elastic Specific gravity—2 6 2 8

The formation of chlorites is linked up chiefly with metamorphism

Glauconite is similar in composition to ferruginous micas (lepidomelane) from which it is distinguished by its smaller K_2O content and higher water and iron content The crystalline structure of glauconite has been little studied It is found in the form of small spheroidal rounded

granules in beds of sedimentary rocks of marine origin Its colour varies from green to dark green It has a dull lustre Hardness—2 3 Specific gravity—2 2 2 8

Glauconite is used as a potassic fertiliser as green paint, and for softening hard water

Complex tectocrystalline structures are obtained when there is a spatial link up of silico oxygenous tetrahedrons In tectosilicates a part of the silicon is always replaced by aluminium and therefore all of them are alumosilicates Among minerals possessing this texture feldspars are the most widespread

Feldspars crystallise in the triclinic or monoclinic system They are brightly coloured have a 6 6 5 hardness a vitreous lustre a medium and perfect cleavage in two planes at an angle near to 90 and a specific gravity of 2 5 2 7

They are divided into two subgroups in accordance with their chemical composition a) soda potash feldspars or anorthoclases and b) lime soda feldspars or plagioclases

Orthoclase [$K(AlSi_3O_8)$] is the most widespread mineral of the first subgroup it always contains a certain amount of Na_2O as an impurity It crystallises in tabular crystals of the monoclinic system It is an essential constituent of several magmatic vein rocks and metamorphic rocks Its colour varies from nearly white to different tints of pink yellow and blood red Cleavage—in two planes at an angle of 90° (hence the name orthoclase from the Greek *orthos* [straight] +*klasis* [fracture]) in one plane the cleavage is perfect and in the other it is medium Hardness—6 Specific gravity—2 5

A *mineral of the same composition* but which crystallises in the triclinic system is called *microcline* (meaning slightly deflected) The angle between the planes of cleavage of this mineral is 20 smaller than a right angle Outwardly microcline cannot be distinguished from orthoclase and can only be identified if it is bright green or blue green The latter variety is called *amazonite* Common potash feldspars (orthoclases) are used in the glass and ceramics industries

A plagioclase subgroup consists of minerals that are a hard solution of two molecules of $Na(AlSi_3O_8)$ and

$Ca(Al_2Si_2O_8)$ mixed in any ratio thus forming a series of com pounds (isomorphous mixtures) with continuously changing composition and properties The extreme members of this series of minerals are called *albite* (sodium aluminium silicate) and *anorthite* (calcium aluminium silicate) Between them are oligoclase andesite labradorite and bytownite all of which contain sodium and calcium molecules in different ratios

Plagioclases are the ingredients of several magmatic and metamorphic rocks All plagioclases crystallise in the triclinic system Separate crystals are seldom found Com plex twinning of crystals is a characteristic feature of pla gioclases This can often be seen on the surface of large crystals in the form of a fine parallel striation

Macroscopically plagioclases differ slightly from each other and form soda-potash feldspars In some cases it is possible to distinguish plagioclase from minerals of the orthoclase subgroup by its colour which is light grey or greenish grey while the latter are pink or yellow There is also a difference in the arrangement of the cleavage planes which in plagioclases form an angle of 86°24 86 50 hence the name from the Greek *plagios* (oblique)+*klasis* (fracture) The twin striation mentioned above sometimes makes it possible to identify plagioclase In many cases it is almost impossible to differentiate between orthoclase and plagioclase with the naked eye and in field conditions there is no alternative but to identify the mineral simply as feldspar

The composition of plagioclase can be quickly and accu rately determined with a polarising microscope fitted with a Fyodorov universal stage this is known as the Fyodorov method

Minerals of the *feldspathoid* group differ from feldspars in that they have a smaller content of silica, and therefore replace the latter as it were in alkaline rocks which formed from magma with a low silica content

Nepheline [$Na(AlSiO_4)$] crystallises in the hexagonal sys tem It is grey green grey red grey to red-brown and blood red The fracture is uneven and has a greasy lustre The cleavage is imperfect Hardness—6 Specific gravity—2 6 Nepheline is never found together with quartz

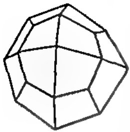

Fig 20 Leucite crystal

It is a rock forming mineral taking part in the formation of alkaline rocks

It is used in the ceramics and glass industries and as a source of aluminium oxide sodium carbonate and so on

Leucite [$K(AlSi_2O_6)$] crystallises in the cubic system It is usually found as regular crystalline phenocrysts in the form of tetragonal trioctahedrons (Fig 20) It is colourless white or light grey and has a vitreous and faintly greasy lustre The fracture is uneven conchoidal Hardness—5 6 Specific gravity—2 45 2 5 Leucite can be used as a potassic raw material

GENERAL INFORMATION ON ROCKS

Rocks of which the Earth s crust is composed are aggregations of minerals of more or less constant composition

A rock may consist of one or several minerals Examples of monomineral rock are marble which consists of crystalline grains of calcite quartzite which consists of only one mineral quartz and gypsum But in nature we most often find polymineral rocks for instance granite which consists chiefly of quartz feldspar and biotite and syenite which consists of feldspar hornblende and mica

In view of the numerous minerals that are known to exist in the Earth s crust there should have been an infinite number of rocks Actually however there are much fewer rocks than minerals The reason for this is that rocks form indefinite physico chemical conditions related to a definite stage of the geological process Only a strictly limited number of minerals existing in stable equilibrium can form under given conditions

We can single out the principal *rock forming* minerals that form rocks and determine all their properties, and accessory minerals whose presence or absence does not alter the nature of a rock

Besides their mineralogical composition rocks are distinguished from each other by their structure and texture

By the term *structure*, we mean the structure of the mineral aggregate i e the degree of crystallinity the shape of the crystals and the size of the mineral grains of which a given rock is formed The structure depends on the conditions in which the rock is formed The composition of a rock i e the arrangement of the minerals of which it is composed is known as its *texture*

According to their origin all rocks are divided into three groups

magmatic rocks which form when chilled magma crystallises

sedimentary rocks, which form on the Earth s surface as a result of the destruction of earlier rocks and of the subsequent mechanical or chemical deposition of the products of this destruction, and also thanks to the vital activity of plants and animals

metamorphic rocks which form at the expense of magmatic or sedimentary rocks under the action of high temperatures and pressures and also thanks to the addition of different gaseous substances which emanate from a neighbouring magmatic chamber

We shall now discuss the characteristics of the most widely occurring rocks

Magmatic Rocks

Depending on the conditions, in which magma solidifies magmatic rocks are divided into two groups *deep seated* or *intrusive* rocks, which formed during the solidification of magma deep in the Earth s crust and *effusive* rocks which owe their formation to the solidification of magma poured out or ejected to the Earth s surface i e lava Moreover there is an intermediate group of semi abyssal rocks which were formed during the solidification of magma near the Earth s surface

The mineralogical composition of intrusive and effusive rocks depends on the chemical composition of magma

All magmatic rocks are divided into four groups depending on the percentage of silicon oxide in them acid rocks with a 65 75 per cent content of SiO_2 average igneous rocks with a 55 65 per cent content of SiO_2 basic rocks with a 45 55 per cent content of SiO and ultra basic rocks with a SiO content of less than 45 per cent

There is such a considerable quantity of silica in acid rock that the surplus is exuded in the form of quartz In average igneous rocks the quantity of silica is equal to the quantity of cations and therefore there is usually no quartz at all or only a small quantity of it in these rocks In basic rocks the quantity of silica is less than the quantity of cations These rocks contain minerals of the silicate group which have a relatively small silicon oxide content and also olivine Lastly in the ultra basic group the quantity of silica is very small Minerals with a poor silica content mainly olivine and pyroxenes predominate in these rocks

Magmatic rocks differ from each other as regards their structure and texture this being due to the different physico chemical conditions that obtained when they were formed

In deep seated layers of the Earth magma solidifies slowly as the temperature and pressure gradually drop and volatile substances (mineralising agents) stimulating crystallisation appear This results in the formation of rocks *consisting entirely of crystals* i e with a *holocrystalline* structure

When magma pours out to the Earth s surface in the form of lava the temperature and pressure drop sharply and this causes a decrease in the amount of mineralising agents i e conditions unfavourable for crystallisation are created This results in the formation of a rock with a *glassy* structure or a microcrystalline rock mass whose crystals can be seen only under microscope This is known as an *aphanitic* structure Moreover a *porphyritic* structure whose features are the presence of phenocrysts of separate relatively large crystals against a general background of a fine grained body of rock is also typical of effusive rocks The reason for the appearance of this kind of structure is that as magma rises to the surface separate minerals have *the opportunity to effloresce while the basic rock mass*

solidifies quickly after lava emerges to the Earth's surface (Fig 21)

A *porphyritic* structure and less often *microcrystalline* and *aphanitic* structure are characteristic of semi abyssal rocks

Magmatic rocks have mainly a *massive* or compact texture which we find in intrusive and effusive rocks or a

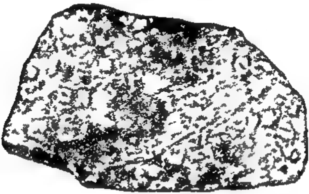

Fig 21 Porphyrite Porphyritic structure

porous texture which is due to the presence of gases in the solidified magma (this is a feature of effusive rocks only)

The conditions in which rocks formed can thus be determined by their structure and texture

The colour of a rock which is determined by the ratio of bright silicates (feldspar) and dark silicates (ferromagnesian) is a very important diagnostic feature of igneous rocks

In determining magmatic rocks it is essential to be able to estimate the specific gravity of these rocks by weighing them in the palm of your hand here the specific gravity ranges from 2 5 2 7 for acid rocks to 3 1 3 25 for ultra basic rocks

Macroscopically magmatic rocks can only be identified approximately in a general way to obtain exact data one needs a microscope

Table 3

Principal Magmatic Rocks
(after A. Iavlov)

Acidity	SiO_2	Acidity indicator mineral	Dark coloured silicates	Rocks with bright silicates			Rocks without bright silicates
				with orthoclase	with nepheline	with plagioclase	
Acid rocks	65-75	Quartz	Biotite Hornblende Augite	Liparite *Quartz porphyry* Granite		Dacite *Quartz porphyrite* Quartz diorite*	
Average igneous rocks	55-65		Hornblende Biotite Augite	Trachyte *Orthophyre* Syenite	Nepheline syenite**	Andesite *Porphyrite* Diorite	
Basic rocks	45-55		Augite Hornblende			Basalt *Diabase* Gabbro	
Ultra basic rocks	< 45	Olivine	Augite				Dunite Peridotite Pyroxenite

* Notwithstanding sizable amount of free quartz in the quartz diorite and its effusive analogues, the percentage of silicon oxide is small (about 63 per cent); this brings quartz diorite close to average igneous rocks. A small percentage of silicon oxide indicates the presence of *basic plagioclase* in the quartz diorite.

** Nepheline syenite and its effusive analogues are, according to present day views, separated into an independent group of alkaline rocks containing about 50 per cent silicon oxide.

A table of principal magmatic rocks (Table 3), which is a useful aid in identifying them macroscopically has been compiled by the Soviet Academician A Pavlov

With this table magmatic rocks are identified as follows

1 Determining a rock s acidity A rock containing quartz (SiO_2) can be classified as an acid rock (Column 3) A rock containing olivine [$(Mg\ Fe)_2\ SiO_4$] can be classified as an ultra basic rock

The identification of average igneous and basic rocks is somewhat more complicated These rocks may contain little or no quartz or olivine at all In the latter case one has to distinguish these rocks by their colour in average igneous rocks there is a predominance of light-coloured minerals or an uncrystallised ground mass while in basic rocks the predominant colours are dark This conforms with the general law governing the distribution of colour in magmatic rocks among which a gradual change from light to dark is observed as we run down from acid to ultra basic rocks

2 Identification of a light coloured mineral in a rock s composition allows us to place it in Column 5 6 or 7 of the table given above Rocks which do not contain light-coloured minerals are placed in Column 8 Where rocks have a cryptocrystalline or aphanitic structure it is hard and sometimes impossible to identify a light coloured mineral visually

3 When we have determined a rock s acidity and have identified a light coloured mineral in it we shall find that this brings us to some square of the table For example identification of an average igneous rock containing plagioclase brings us to the square with three rock denominations andesite porphyrite and diorite All these rocks formed from one and the same magma and have a similar composition Their difference is determined by the conditions in which magma had solidified

The rocks named in the table in bold type are abyssal (intrusive) rocks those named in conventional type and in italics are effusive rocks; semi-abyssal rocks are also named in italics

4 Identification of the structure of a rock allows us to classify it either as intrusive or effusive If the rock is in

trusive its name is determined at once (in our example—diorite); if it is effusive, the identification is continued.

5. The degree of alteration of effusive rocks leads to essential distinctions in their texture and partly in their mineralogical composition, thus enabling us to single out fresh looking, insignificantly altered *neotype* rocks, and greatly altered *paleotype* rocks. The former are named in the table in conventional type, the latter in italics.

The texture of neotype rocks is usually porous, and that of paleotype rocks—compact; if there are crystalline phenocrysts, it may be noted that in paleotype rocks they have been greatly disintegrated (light coloured silicates change into kaolinite). Due to various chemical reactions the colour of the ground mass frequently changes as well becoming darker in paleotype rocks.

6. Column 4 names the dark-coloured silicates occurring most frequently in groups of rocks of a definite acidity. They are arranged from top to bottom in the order of their predominance in one group or another. Thus, in acid rocks biotite is the most common, while hornblende occurs less frequently and augite still less frequently.

The identification of magmatic rocks may be considered as complete when the characteristics of the dark coloured minerals have been determined.

It should be borne in mind that only the most typical rocks are listed in the table. In nature there are many rocks which by their composition are transitional between the rocks in the table.

The commonest of these are described below.

Ultra-Basic Rocks. These are intrusive holocrystalline formations. They have a high specific gravity (about 3.25) which is due to their mineralogical composition. Olivine and pyroxenes are the minerals forming ultra basic rocks. These rocks contain practically no other minerals of the silicate class. Peridotite, pyroxenite and dunite are representatives of this group of rocks.

Peridotite consists basically of olivine. There is also a sizable quantity of pyroxenes.

Dunite consists basically of olivine; chromite and magnetite are present in small amounts. This rock often contains native platinum.

Pyroxenite—pyroxenes are the dominant minerals, olivine is present in a small amount Peridotites and pyroxenites usually contain iron chromium and nickel ores

Basic Rocks Pyroxenes (augite) and plagioclases (close to anorthite, often labradorite) are the principal minerals forming basic rocks in addition hornblende and less often, olivine may be present Dark-coloured minerals give the rock its dark hue, the dark grey grains of plagioclases standing out against this dark background Gabbro basalt and diabase are representatives of this group of rocks

Gabbro is an intrusive holocrystalline rock consisting of dark pyroxene (augite) or hornblende crystals and light-coloured plagioclase crystals The latter are often represented by labradorite which shows a beautiful play of blue and green Labradoritite which consists almost entirely of labradorite is a variety of gabbro Gabbroid rocks are linked up with titano magnetite and copper deposits

Basalt and diabase are effusive analogues of gabbro

Basalt is a black rock with a cryptocrystalline or microcrystalline structure In this rock there is usually a non crystallised glassy mass side by side with small crystals of augite plagioclase and olivine Against the dark background of this mass augite and olivine stand out in the form of small occasionally dotted shining phenocrysts

Diabase has the same structure and mineralogical composition as basalt but on account of secondary changes a part of its components—olivine pyroxenes and amphiboles—transforms into green hornblende, serpentine and chlorite this gives the rock its dark greenish grey hue

Average Igneous Rocks In average igneous rocks there are more light coloured than dark coloured minerals Of the dark silicates, the most typical are biotite hornblende and, less frequently, augite This ratio of minerals gives average igneous rocks their light colour against the background of which dark hued phenocrysts stand out

Diorite is an intrusive rock with a holocrystalline structure Light coloured minerals are represented by plagioclases (from andesite to oligoclase) to which the rock owes its light grey or green grey colour, that forms a background for crystals of dark minerals chiefly hornblende Some

diorites may contain quartz in which case they are called *quartz diorites* Commercial deposits of lead zinc and copper sulphides are often linked up with diorites Skarn iron ores are formed where diorites are in contact with limestones

Effusive analogues of diorite are andesite and porphyrite and those of quartz diorite are dacite and quartz porphyrite

Andesite has a porphyritic structure The cryptocrystalline ground mass is porous and of a light grey or light brown colour Shining phenocrysts of medium plagioclases (andesite) hornblende or augite frequently stand out

Porphyrite has the same structure and mineral composition as andesite and is the latter's paleotype analogue Porphyrite has a more compact texture the colour of the ground mass is darker and the plagioclase phenocrysts are in a worse state of preservation with the result that they frequently lose their vitreous lustre and acquire an earthy fracture

Syenite is an intrusive rock Its principal minerals are soda potash feldspars (orthoclase and microcline) and to a lesser extent hornblende which is partly replaced by biotite and occasionally by augite Its structure is holo crystalline usually medium grained

Trachyte and orthophyre are effusive analogues of syenite

Trachyte is a light yellow or pinkish porous rock with a porphyritic structure Crystalline phenocrysts are represented by sanidine a shining water transparent variety of orthoclase and occasionally by dark coloured minerals

Alkaline Rocks These rocks are characterised by a relatively low content of silicon oxide (40 50 per cent) and a considerable content of alkalis (up to 20 per cent)

Nepheline syenite is a bright coarse grained intrusive rock Its essential components are alkaline feldspars and nepheline the latter being easily identified by the uneven fracture and the dull or faintly greasy lustre Of dark coloured minerals this rock contains alkaline amphiboles and pyroxenes

Effusive analogues of nepheline syenite occur very rarely

Acid Rocks All acid rocks are characterised by the presence of quartz and large quantities of feldspars (orthoclase), which give the rocks a light colour and account for their low specific gravity (about 2 7)

Granite is an intrusive rock with a holocrystalline, usually medium grained or occasionally coarse- or fine grained structure Here the rock forming minerals are quartz common potash feldspars (orthoclase and microcline) less frequently acid plagioclase and one or several dark coloured minerals—biotite, which in some varieties is replaced by muscovite less frequently hornblende and still less frequently pyroxene (augite)

In a quantitative respect the leading role is played by common potash feldspars which are sometimes partially replaced by plagioclase Feldspars are easily distinguished by their cleavage vitreous lustre and colour which is usually red white or greyish yellow Quartz is present in the form of colourless or smoky grey (up to black) grains of irregular shape with a greasy lustre and an uneven or conchoidal fracture If together with biotite granite contains muscovite it is called binary granite

Under the influence of hot vapours and volatile compounds penetrating along fissures from a magmatic chamber, granite may transform into a feldspar free quartz micaceous rock called *greisen* This rock is linked up with deposits of tin tungsten and, less frequently of molybdenum and arsenic

Effusive analogues of granite are liparite and quartz-porphyry

Liparite has an aphanitic or porphyritic structure The light coloured frequently white glassy or aphanitic groundmass contains sparse feldspar, quartz and biotite phenocrysts

Quartz porphyry is a transformed liparite and has a compact more or less dark (brown brown red brown yellow or grey) ground mass impregnated with greatly disintegrated orthoclase and shiny quartz crystals Phenocrysts of dark minerals are seldom present

Besides the rocks named in A Pavlov's table and described above mention must be made of a number of other rocks whose formation is likewise associated with magma

Pegmatites are vein rocks that formed during the last stage of the solidification of magma enriched with volatile substances. Pegmatites associated with acid granite magma are the most common. They are distinguished by their macrocrystalline structure: *in some cases elongated crystals of* quartz and feldspar are intertwined with the result that a

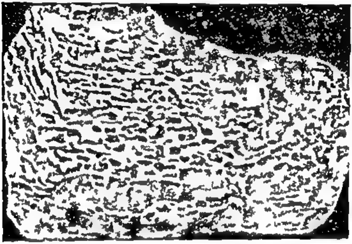

Fig. 22. Pegmatite (graphic granite)

pattern reminiscent of ancient hieroglyphs appears on the cleavage faces. This variety of pegmatite is called graphic granite (Fig. 22).

Pegmatites consist chiefly of feldspar and quartz, though they may also contain mica. These rocks are linked up with deposits of feldspar, mica and quartz as well as of many rare and radioactive minerals.

Obsidian or *volcanic glass* is a homogeneous crystal-free mass of *different chemical composition*. The most common obsidians took shape during the cooling of acid lava. They are usually of a dark colour (up to black) and have a vitreous lustre and a conchoidal fracture.

Pumice is a porous non-crystalline rock which formed during volcanic eruptions of gas-rich magma. Because of

its porous structure pumice has a very low specific gravity (it floats in water)

Also owing their formation to volcanic eruptions is a group of rocks known as pyroclastic rocks When volcanoes erupt tiny particles of molten lava rock and mineral debris are ejected into the air together with water vapours and gases Loose accumulations of such particles form *volcanic ash* or *volcanic sand* (depending on the size of the particles) Larger fragments known as *lapilli* (small stones) and *volcanic bombs* are also ejected Cemented volcanic ash and sand form a compact rock called *volcanic tuff* which often contains larger fragments

Sedimentary Rocks

As distinct from magmatic rocks sedimentary rocks are formed on the surface of the lithosphere surface as a result of the action of water, air or the organic kingdom

While the interior of the lithosphere consists almost entirely of magmatic rocks 70 per cent of its surface mass is composed of sedimentary rocks The sedimentary mantle is in general not thick In some places it is only several score or hundreds of metres thick but in certain areas of the Earth s crust sedimentary rocks reach a thickness of 15 20 kilometres

These rocks occur in a loose state and also in a compact or solid state Loose rocks are either dry, as for instance sand or being compact in a dry state readily absorb moisture as for instance, clay

Sedimentary rocks may be either loose or cemented For example sand may turn into sandstone and gravels may become conglomerate In the case of cemented rocks the composition strength and density of the cementing agent should be determined The composition of the cementing agent may vary Mostly it is composed of different chemical compounds precipitating from the water circulating between fragments It may be a) calciferous which is identified by reaction with hydrochloric acid b) silicic which is identified by its great hardness and sometimes lustre c) ferriferous which is identified by a characteristic yellow red

or brown colour and by a high specific gravity d) clayey which gets oaked quite easily and so forth

It is of great practical importance to determine the porosity of loose sedimentary rocks which shows the degree these rocks are permeable by water oil and so on

Porosity varies with the type of rock For example, in the case of sand porosity varies from 28 to 40 per cent

Fig 23 Stratification of sedimentary rocks

the average being about 30 32 per cent in clays it often exceeds 50 55 per cent Some hard (monolithic) rocks are al o porous but their porosity is considerably lower for in tance in lime tones

Many sedimentary rocks are stratified The formation of a layer is connected with the conditions of edimentation A light change in the e conditions leads to changes in the depo ited material an outward manifestation of this is the appearance of different layers (Fig 23) in a rock The layers are distingui hed from each other by the composition, the size colour and den ity of the structure of the min

eral grains In some cases, all these features exist simultaneously, i e the composition, colour size of grains and density of one layer differ from those of another

Depending on the conditions of sedimentation, we can differentiate between normal (horizontal or nearly horizontal), cross diagonal and other beddings There are sedimentary rocks in which no stratification is observed for instance, limestones deposited in the sea as a result of the vital activity of reef building corals and plants

On the basis of their origin, sedimentary rocks are divided into three main groups

1 fragmentary or clastic rocks which owe their formation to the mechanical disintegration of rocks and the accumulation of rock fragments

2 chemical rocks which were formed through the precipitation of substances from solutions

3 organogenic rocks which took shape as a result of the vital activity of organisms

When as in the case of magmatic rocks sedimentary rocks are identified attention should be paid to their mineralogical composition and structure The mineralogical composition is an indicator of only chemical and organogenic rocks clastic rocks may contain fragments of a variety of minerals and rocks The make up of sedimentary rocks is shown by their structure which is defined chiefly by the size and shape of the fragments or crystals, and by the texture i e, the arrangement of these fragments in the rock

A description of the most common sedimentary rocks is given below

Fragmentary Rocks

According to the size of the fragments in them these rocks are divided into the following groups

a) rudaceous or psephitic rocks consisting of fragments with a diameter of over 2 mm

b) arenaceous or psammitic rocks consisting of fragments with a diameter of from 0 05 to 2 mm

c) micro-fragmental or powder rocks (aleurite) consisting of fragments with a diameter of from 0 01 to 0 05 mm

d) fine fragmental (argillaceous pelitic) rocks consisting of fragments with a diameter of less than 0 01 mm

Several classifications of clastic rocks in which the above mentioned sizes of the fragments slightly varied have been *proposed*

Rudaceous or Psephitic Rocks

These rocks consist of fragments with a diameter of from 2 millimetres to several metres Depending on the size and shape of the fragments and on the texture they are classified as follows

Blocks—angular fragments with a diameter of over 100 millimetres

Rock waste—angular fragments with a diameter of from 10 to 100 millimetres

Landwaste—angular fragments with a diameter of from 2 to 10 millimetres

Boulders—rounded rolled fragments with a diameter of over 100 millimetres

Pebbles—rounded rolled fragments with a diameter of from 10 to 100 millimetres

Gravel—rounded rolled fragments with a diameter of from 2 to 10 millimetres

Rocks consisting of cemented unrounded fragments are called *breccia* If the rolled fragments are cemented together the rock is called *conglomerate*

When identifying psephitic rocks attention should be paid to 1) *the composition of the fragments* 2) *the shape* of the fragments if they are rounded their shape should be studied in detail because this will help to elucidate their origin (for example marine pebbles are usually flat while river pebbles are egg shaped) 3) the size of the fragments if the rock is composed of *fragments of different* size the range of the diameters and the dominant size should be indicated 4) if the rocks are cemented attention should be paid to the composition density and strength of the cementing agent

Arenaceous or Psammitic Rocks

Sand and sandstones which are very widespread, are arenaceous rocks

Sands are loose or compact rocks consisting of fragments with a diameter of from 0 05 to 2 millimetres In *sandstones* fragments of the same size are cemented together

Depending on the size of the fragments sands and sandstones are divided into coarse sands coarse grained sands medium grained sands fine sands and fine-grained sands For the composition of the fragments in them they are often quartzose because chemically quartz is the most stable mineral Grains of feldspars mica, glauconite carbonates and other minerals may be mixed with the quartz grains If one of these minerals predominates in the rock the name of this mineral is added to the word sand (for example glauconitic or green sand, micaceous sand, quartz sand feldspar or arcose sand) Depending on the composition of the cement sandstones can be called ferruginous calcareous siliceous and so on

Sands and sandstones are identified in the same way as psephitic rocks

Microfragmental Rocks

Loess and loess like loams are typical representatives of these rocks

Loess is light yellow or straw yellow rock composed chiefly of 0 01-0 05 millimetre quartz and feldspar particles with an admixture of clay particles and lime The latter is present in rock either in the form of small, rounded particles (lime nodules) or in the form of diffuse dust, either of which can be easily detected with the aid of hydrochloric acid which causes loess to boil Loess is easily pulverised into a fine mealy powder It has a high porosity (40-50 per cent) and *is* pervious to water Where huge masses of loess accumulate they form high vertical cliffs in rain channels and depressions In a dry state loess is durable and withstands big loads (heavy constructions)

Wet loess loses the bonding between the constituent fragments and grows compact with the result that cracks

and subsidences form on its surface Roughly up to 10 per cent of volume is lost when moisture is absorbed and this leads to the destruction of the structures erected on loess

Many scientists are of the opinion that the *formation* of loess is due to eolian (wind borne) action However recent studies in the U S S R show that in various regions loess is of different origin It can be formed of sediments deposited not only by the wind but also through the action of water and as a result of eluvial processes

Loess like loams are distinguished from loess by the inclusion of considerable quantities of minute particles in addition to coarse (0 01 0 05 millimetre) dust particles Loess like loams are frequently very porous and contain carbonates like loess some loams decrease in volume when they absorb moisture If the content of clay particles (less than 0 001 millimetre) is high these loams do not subside

A number of sandy argillaceous rocks (*sandy loams and loams*) belong to this group

Fine Fragmental Rocks

Common clays which are partially products of the accumulation of minute mechanical particles and partially products of the chemical decomposition of other rocks are fine fragmental rocks Kaolinite and montmorillonite are the most typical minerals of which clay is formed Clay composed of kaolinite is called kaolin and in the absence of ectogenic impurities it is white Clay composed chiefly of montmorillonite is called bentonite and its colour ranges from white to greyish green

When identifying the colour of clay attention should be paid to the moisture content because the colour of dry clay is not as intense as that of damp clay In a dry state clay energetically absorbs moisture and becomes water-resisting a property that sharply distinguishes it from sand through which water freely percolates Dry clay is earthy and is easily ground into powder in a moist state it is plastic and takes any shape imparted to it preserving

this shape after drying A shiny streak will be left on the surface of clay if a line is drawn with a finger nail

Clays that melt at a temperature of approximately 1 700°C are called refractory clays Some varieties of clays excellently absorb grease and oil and are for that reason used as fulling clays for cleaning grease from wool and broadcloth

In nature clay may be mixed with sand such clay is called *loam* If loam contains gravel rock waste and boulders it is called *boulder loam* Lithified boulder loam is called *tillite* Clay with a high content of carbonate of lime is called *clay marl*

Consolidated clay rock which is hard to break and absorbs little moisture is called *argillite*

Chemical and Organogenic Rocks

Chemical and organogenic rocks which form mainly in water basins are interconnected by a number of transitions In some cases it is rather difficult to establish the affiliation of a rock to any of the above mentioned groups

The structure of chemical rocks is determined by the size of the crystals of the constituent minerals (coarse grained medium grained close grained or fine grained) while that of organogenic rocks by the preservation of the constituent remains or by the affiliation of the latter to some organism

Chemical and organogenic rocks are usually classified according to their chemical composition

Carbonaceous Rocks

Limestone consisting of calcite is the most common of these rocks All the properties characteristic of calcite can be used to identify limestone The most exact indication is the reaction with hydrochloric acid Limestones are usually white or light yellow but the colour can be changed up to black by impurities Limestones are of organogenic

or chemical origin In the former case the rock consists of organic remains which are not always detectable with the naked eye The organic remains may be intact or shattered Attention should be paid to the degree of preservation as this indicates the conditions in which the sediment was deposited For example limestone consisting of small fragments of shells formed during a turbulent movement of water on the bed of a basin while sedimentation was in progress i e in shoal water conditions

If it is possible to identify the remains of which the limestone consists these remains give their name to the limestone for instance fusulina coral brachiopod limestone and so on Limestones consisting of mollusks shells are called coquina (shell limestones) Chalk is a special type of organogenic limestone and usually consists of tiny shells or shell fragments of foraminifera and of the calcareous skeletons of microscopic algae

Of the limestones of chemical origin the following varieties are distinguished

1) compact fine crystalline aggregations—*compact or massive limestone*—whose crystalline structure can be determined only by a microscope

2) *oolitic limestones*—aggregations of fine spherules with a conchoidal or radiated structure and held together by calcareous cement

3) *tufa* or *travertine*—highly porous aggregations consisting of microcrystalline calcite this rock is formed where ground waters seep through to the surface the surplus of dissolved calcium carbonate precipitates from these waters and forms a porous rock

4) the formation of *stalactites* and *stalagmites* which are sinter forms of calcite is linked up with underground waters they hang from the ceilings of subsurface caves and rise from their floors their fracture is usually coarse grained

Marl is a rock composed of calcite and clay particles (30 50 per cent) Outwardly it resembles limestone Its chief characteristic is the reaction with hydrochloric acid which leaves a spot on its surface This spot is the result of a concentration of clay particles where the reaction had taken place

Dolomite is a rock composed chiefly of the mineral of the same name Outwardly it resembles limestone and differs from it by a weak reaction with hydrochloric acid (see mineral dolomite) It is formed mainly through a chemical transformation of calcareous sediments with which it is connected by several transitional rocks, and through precipitation from aqueous solutions

Siliceous Rocks

Siliceous rocks can also be of chemical or organogenic origin One of the latter type is *diatomite* which is a very light white or light yellow rock It is a soiling rock which is easily ground into fine powder and is composed of the tiny opaline skeletons of diatoms

Outwardly there is hardly any difference between *tripolite* and *diatomite* The former consists of small opal grains with an admixture of diatom shells and the remains of the siliceous skeletons of radiolarians and sponges Its characteristic features are a low specific gravity (which is easily determined by weighing a fragment of this rock in the palm of the hand) and an ability to absorb moisture avidly (sticks to the tongue)

Opoka is a hard white or grey to black rock with a conchoidal fracture When struck the hardest varieties break with a specific ringing sound This rock has a somewhat higher specific gravity than tripolite Investigations with a microscope showed that like tripolite opoka consists of opal granules and the remains of the siliceous skeletons of various organisms cemented by siliceous material This rock is possibly the product of the transformation of diatomite and tripolite

Siliceous sinters or *geyserites* are a light multicoloured rock that forms round the outcrops of hot springs whose waters are saturated with silica

Ferruginous Rocks

These rocks include iron protoxide and iron oxide which formed on the Earth's surface in lakes and bogs as well as in the turf level of meadow mantles These deposits

known as *ferruginous tuff* are quite widespread and often form beds of lacustrine bog or meadow ore which may be used for the manufacture of iron

Halogen and Sulphate Rocks

Halogen and sulphate rocks are of chemical origin The most common halogen rock is *rock salt* which usually forms light coloured crystalline aggregations consisting of mineral halite The colour of this rock depends on the different mostly mechanical impurities in them Deposits of rock salt are often very large and form an important base for the chemical industry Rock salt frequently alternates with *anhydrite* ($CaSO_4$) *and complex compounds* containing potassium sodium and magnesium

Gypsum is a widespread rock It may be coarse grained fine grained or sometimes fibrous (selenite) it is usually white but sometimes it may be pink blue or some other light colour

Carbonates borates and sulphates of potassium and sodium occur less frequently but are important economically For example there are lakes with deposits of *carbonate of sodium* (in Western Siberia the Transbaikal Area Georgia) and *borates* (around Lake Indera) There are deposits of *saltpetre* in the Doronino chain of lakes in the Transbaikal Area *Mirabilite* is produced in Kara Bogaz Gol on the Caspian Sea

Bauxites

Bauxite is a rock composed chiefly of aluminium hydroxide ($Al_2O_3 \cdot 2H_2O$) Usually it is a light yellow red brown red or occasionally white earthy or oolitic mass It is a very important aluminium ore

Caustobioliths

Caustobioliths or combustible rocks are formed organogenically and consist of organic compounds Most of them are of great economic importance The most widespread of

these are coals representing various degrees of the decay of vegetable remains

Peat is a more or less loose, yellow brown or black rock composed of visible vegetable remains It is formed during the partial putrefaction of vegetation in aqueous conditions with an insufficient inflow of oxygen Of the caustobioliths peat has the lowest carbon content (52 62 per cent)

Brown coal (lignite) is a rock which was formed as a result of the decomposition of plants in the absence of air which led to the accumulation of about 70 per cent carbon It is a compact dark brown or black mass with an earthy or rarely a conchoidal fracture and usually a dull lustre Its streak is dark brown

Coal contains up to 82 per cent carbon It is a black rock which is more compact than lignite and has an earthy or conchoidal fracture, a dull lustre and a black streak (soils hands)

Anthracite is formed as a result of a deep metamorphism of coals under the influence of high temperatures and pressures and contains up to 95 per cent carbon It is a very hard greyish black rock with a strong submetallic lustre Its fracture is uneven, conchoidal It is a compact rock and does not soil hands

Combustible shales are a rock of mixed origin (clastic and organic) formed on the floor of basins during the simultaneous precipitation of clay particles and fine organic ooze (sapropel) Combustible shales are thinly laminated have a dark grey or brown hue, and give off a bituminous odour when they are burned

Economically important rocks such as petroleum and the products of its alteration (asphalt and ozokerite) are also classed as caustobioliths

It has been established that *petroleum* is a product of the decay of plant and animal remains Several hypotheses have been advanced to explain its origin The most probable one is that sapropel (putrid silt) which accumulates on the floor of lagoons or in river deltas at the expense of organic remains is its source material The further transformation of sapropel under high pressures and temperatures leads to the formation of gaseous and liquid hydrocarbons of which petroleum is composed Pressure causes

the oil to migrate into overlying strata where it accumulates in porous rocks (sands sandstones some varieties of limestones) Present day oil deposits are related to the e rocks

Petroleum is a complex mixture of liquid and gaseous hydrocarbons Outwardly it is a light oily liquid with a specific odour Depending on the composition the colour varies from nearly white yellow and red brown to dark brown and correspondingly its specific gravity varies from 0 76 to 1 0

Asphalt and *ozokerite* or *mineral wax* are also mixtures of hydrocarbons and are products of the metamorphosis of different oils (the former of naphthene oils and the latter of paraffine base oils) Outwardly they can hardly be distinguished from each other both are brown or black compact aggregations with a greasy lustre and a bituminous odour Each has a different specific gravity asphalt—1 1 2 ozokerite—0 8 0 97

Metamorphic Rocks

Metamorphic rocks are formed in deep seated layers of the Earth through the recrystallisation of magmatic and sedimentary rocks under the influence of high temperatures and pressures and also during the interaction of these rocks with the hot gases emanating from magma These processes result in a metamorphosis of the primary structure and texture of the rock and of its mineralogical and chemical composition Metamorphosis may take place 1) when mountains fold during an intense contraction of rocks 2) when mountains subside into deeper zones where they come under the pressure of overlying beds and the influence of high temperatures 3) during contact with magma

Metamorphic rocks have a holocrystalline structure and foliated banded or fibrous texture The origin of these textures is associated with the perpendicular orientation of the long axes of the minerals to the actual pressure

The following are the widespread metamorphic rocks

Gneisses are banded and schistose rocks consisting of quartz feldspar and mica or hornblende Biotite muscо

vite and mica gneisses also occur Gneisses may form as a result of the metamorphism of magmatic rocks (orthogneisses) or though the transformation of sedimentary rocks (paragneisses)

Clay shales represent the initial stage of the transformation of argillaceous rocks These transformations are so insignificant that some scientists are inclined to classify clay shales as sedimentary rocks Clay shales are distinguished from the latter by a well defined schistosity in parallel to which the clay shales break easily into blades with a dull lustre

In contrast to other metamorphic rocks their structure is not holocrystalline Outwardly they are similar to clays and like the latter have an earthy fracture and a dull lustre but do not absorb water

Phyllites represent the next stage of the transformation of argillaceous rocks They have a holocrystalline usually fine grained structure that cannot be distinguished with the naked eye but which is manifested in a deep usually silky lustre on the surface of the fracture along the cleavage Phyllites consist of tiny mica and quartz scales

Mica schists are formed as a result of the further metamorphosis of argillaceous rocks They have a well defined holocrystalline structure and a foliated texture and consist of mica and quartz They are distinguished from gneisses by the absence of feldspar Where mica predominates the schist is called muscovite schist, biotite schist and so on

In addition to the rocks enumerated above there are a number of other metamorphic rocks with a holocrystalline structure and a foliated texture These are united under the name of *crystalline schists* Depending on the predominant mineral in them these rocks are known as talc schist chlorite schist and so forth

Chlorite slate or *schist* is composed of scaly schistose grains of chlorite with an admixture of quartz Talc mica feldspar and magnetite are encountered as accessory minerals

Talc schist is composed essentially of talc and has a low hardness a high refractoriness and a greasy feel Talc schist is used as a lubricating material and also for the manufacture of refractory bricks

Hornfels are a metamorphic rock that forms during the contact metamorphosis of argillaceous and effusive basic rocks. They are a white, grey and sometimes pink-grey compact rock with a conchoidal fracture and consist of quartz and amphiboles with an insignificant admixture of biotite, muscovite, apatite and other minerals.

Quartzite consists wholly of recrystallised grains of quartz. It has a holocrystalline generally fine grained structure and a massive, rarely foliated texture. Pure varieties of quartzite are white or light grey, but impurities may change the colour to a red brown, crimson, etc. The formation of quartzite is due to the metamorphosis of quartz sands, sandstones and other siliceous rocks.

Jasper is a hard, compact and bright or multicoloured rock consisting of fine grained quartz or chalcedony. Hematite, epidote, chlorite are present as impurities.

Marble, a transformed carbonate rock, is a typical metamorphic rock. It is mostly massive, seldom shaly, and consists of calcite grains of more or less equal size. Quartz, hornblende, pyroxene, olivine and sometimes feldspar are present as impurities and determine the colour and pattern. Especially pure varieties of fine-grained marble are used in sculpture.

Marbles coloured by various impurities are used as a valuable ornamental stone. In the U.S.S.R. it is quarried extensively in the Urals, Karelia, the Crimea, the Transcaucasus, Central Asia and many other places. Crystalline dolomite is very similar to marble but consists of dolomite grains. Like marble, it is used as a building and ornamental stone.

EXOGENOUS PROCESSES

The Earth's relief is not permanent. It changes constantly as a result of the action of water, wind, temperature fluctuations and so on. These changes in the Earth's topography are due to external or *exogenous* causes.

Let us examine the nature and results of the action of the wind, snow and ice, water flowing on the Earth's surface and migrating into its depths, water in reservoirs and ponds and other external forces. The action of these forces is aimed at flattening out the Earth's surface, destroying mountains by the gradual exposure (denudation) of new rock horizons and transporting demolished material into lower lying areas.

ROCK WEATHERING

Weathering is a collective term uniting the mechanical, chemical and biological (organic) processes that take place on the Earth's surface as a result of temperature fluctuations, the freezing of water, the action of the oxygen and carbon dioxide in the air and atmospheric precipitation, as well as the action of organic acids in the soil. We distinguish between mechanical (physical), chemical and biological weathering, but it is often difficult, if not impossible, to draw a clear distinction between them, in nature they usually act simultaneously.

Mechanical weathering. This is principally due to changes in the temperature of minerals and rocks caused by temperature fluctuations of the air and in some cases by direct heat from the sun. Minerals and rocks expand when they

are heated and contract when they are cooled This expansion and contraction is very negligible but when it is constantly repeated over a period of hundreds and thousands of years it ultimately makes itself felt Under the influence of this repeated contraction and expansion the adhesion between the grains in a rock gradually weakens the coarser the grains the faster the adhesion between them weakens because fine grains do not expand as much as coarse grains The colour of a rock is also important Dark coloured minerals and rocks are heated faster and consequently increase in volume quicker than light coloured minerals and rocks The adhesion between the grains in a motley rock (for instance granite which consists of black red and white minerals) weakens faster than in rocks of a uniform colour This is due to the fact that grains of different colour and composition have their own coefficient of expansion in consequence of which a supplementary stress is set up between them when they expand

Multicoloured coarse grained rocks offer the least resistance to temperature changes Day time heating after a cold night starts a desquamation process while cooling causes rocks to crack In the course of centuries of alternation of contraction and expansion tiny cracks appear in mineral bodies At first invisible to the eye they gradually expand causing monolithic mineral or rock to disintegrate The mechanical disruption of a mineral mass intensifies during sharp diurnal temperature changes Sharp temperature changes are observed in spring and autumn especially in regions with a continental climate for instance deserts where the rock surface is heated in the day time to 70 C and cools down to zero at night In deserts the changes in the volume of minerals are particularly great and physical weathering plays a very important role

Water facilitates the action of heat and cold In rainy weather rocks become wet and then dry again this repeated wetting and drying weakens the adhesion between particles of which rocks consist Water that freezes in the fine pores and cracks of rocks plays an even bigger role Intense temperature changes are observed in the polar regions and they give rise to what is known as frost weathering Water turns into ice when the temperature falls below zero increasing

its volume by one eleventh Thus if during the day when the temperature is above zero water fills a void in some crack it will tend to widen this crack when it freezes during the night

Enormous pressure which sometimes rises to as high as thousands of kilograms per square centimetre is exerted by freezing water on the walls of a crack Therefore in regions with considerable diurnal temperature fluctuations (especially from positive to negative) mechanical weathering manifests itself in a very intensive manner and leads to the formation of *talus* which consists of numerous fragments accumulating at the base and on the slopes of a demolished cliff Taluses are astatic and difficult to traverse On the plane surface of cliffs rocks disintegrate through weathering and turn into continuous placers of boulders

Atmospheric electrical phenomena also influence rocks Lightning breaks up rocks or melts them altogether for instance loose sands forming fulgurites These phenomena are however relatively rare

Chemical Weathering The action of the vapours and gases in the atmosphere and of sun rays leads to chemical changes in the composition of minerals and rocks Water vapours condensed into liquid may contain in solution various substances which increase the solubility of minerals Moisture enriched with organic acids is not only a dissolvent but also starts such intricate processes as hydrolysis and oxidation

To give a clearer idea of chemical weathering we offer a formula showing the decomposition reaction of feldspars under the action of air moisture and carbon dioxide which leads to the formation of soft kaolin (lithomarge) from solid feldspar

$$Na_2O\ Al\ O_3\ 6SiO\ +nH\ O+CO\ =Na\ CO_3+SiO_2\ nH_2O+$$
$$+2H_2O\ Al\ O_3\ 2SiO_2$$

Under the influence of air moisture and oxygen the weathering of sulphurous minerals of pyrite for example proceeds in much the same way, releasing ferrous sulphate and sulphuric acid

$$FeS_2+8H_2O+7O=FeSO_4+7H_2O+H_2SO_4$$

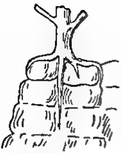

Fig 24 Destruction of a cliff by the roots of a tree

When anhydrous rocks are subject to chemical weathering they sometimes absorb water and develop into hydrates Similarly anhydrite turns into gypsum ($CaSO_4 + 2H_2O = CaSO_4 \cdot 2H_2O$) and iron glance into limonite ($2Fe_2O_3 + 3H_2O = 2Fe_2O_3 \cdot 3H_2O$)

These transformations are very widespread in nature

Sodium carbonate potassium carbonate alkali sulphates colloidal solutions of silica that rapidly dissolve in water are also formed during chemical weathering Penetrating into products of weathering atmospheric water (rain melting snow) dissolves and evacuates them into deeper layers insoluble products of weathering (clay sand rock waste gruss and so on) remain on the surface

Biological or Organic Weathering The presence of micro organisms in the uppermost layers of the Earth s crust increases the intensity of chemical reactions Thus according to V I Vernadsky feldspar yields to biological weathering only when bacteria participate in the process When water and carbon dioxide are the only agents weathering hardly affects feldspar

Organisms alter rocks mechanically and chemically Lichens and mosses colonise the surface of rocks absorb nutrient substances from them and thereby destroy them The roots of plants also destroy rocks mechanically and chemically (Fig 24) Moles ants and earth worms loosen rocks

A weathering crust takes shape during all processes of weathering The immovable part of the weathering crust from which soluble salts are washed away by precipitation is called *eluvium* Where the weathering crust is enriched with the products of the vital activity of various organisms and is partially reworked by them it is called *soil* From the soil plants absorb nitrogen potassium phosphorus calcium suphur iron copper magnesium oxygen hydrogen and other chemical compounds which they need for their nutrition and after they wither they not only return these substances to the soil but also give it the substances

that they had absorbed from the atmosphere. In the process of photosynthesis, plants turn carbon dioxide into starch, cellulose and other organic compounds, which, after the plants die, pass into the soil and undergo further changes—decay, putrefaction and so forth. Plant tissues turn into new compounds that interact with mineral particles. A part of these compounds is accumulated in the soil in the form of humic substances which distinguish soil from rock and make it fertile. The remaining compounds evaporate or are carried away together with water into deeper horizons.

Soil Formation. The vegetative cover plays a prominent role in the formation of soil, and therefore in different climatic and geobotanical conditions of the Earth's surface this process proceeds in different ways. Depending on the type of vegetation and changes that a plant undergoes after its death, different varieties of soil are formed. But because the vegetative cover is connected with climatic conditions, the soil varieties bear the marks of climate. The climate, the vegetative cover and soils are thus interrelated.

According to the late Academician Vasily Williams, soil science or pedology must essentially be considered a chapter of geology devoted to the study of the processes taking place in the surface horizons of the lithosphere immediately contiguous to the atmosphere and hydrosphere with the direct participation of the biosphere.

The necessity of studying the soil as a natural historical body was first advanced by Vasily Dokuchayev, founder of Russian geological pedology, who said that "soil should be called the day or external horizons of rocks (no matter which) that had been transformed naturally through the combined action of water, air and various living and dead organisms." In this connection he singled out natural soil-forming agents among which he included the parent rock, the climate, the vegetation, the topography and the time (the age of the soil). The major tasks of pedology may be formulated as follows: 1) study of the origin of the parent rock under the influence of external geological forces; 2) study of the origin of the soil from the parent rock under the influence of intruding organisms. It is apparent that the soil, as well as the parent rock and all geological

forces (including the organic kingdom) are in a state of constant development. The soil is therefore studied on the basis of genetic and evolutionary principles.

As we have already mentioned, the Earth's surface receives a mantle of soil through complex mechanical, chemical and biological weathering. The soil's fertility is the basic feature distinguishing it from other rocks. By its origin soil is composed of: a) hard mineral particles, b) organic remains, c) a living population, d) ground water and air. Hard particles of soil consist of mineral and organic substances, the former almost always predominating.

In soil the most widespread minerals are quartz, feldspar and mica flakes; calcite, gypsum and ferric oxide are found occasionally. In addition, there are more or less important accumulations of zeolites, clay particles, kaolinite and montmorillonite.

The mineral particles in soil can be distinguished by their size. Therefore, a characterisation of soil must indicate its mechanical composition, i.e. the size of the mineral grains in it. The name of various soils depends on the content of large and small particles in them. There are thus stony, sandy, silty, argillaceous and other soils.

In soil organic matter is usually represented by humus, which gives it various tints of grey, brown and black. Depending on the natural conditions in which soil forms the quantity and type of humus may be different, with the result that the colour of the soil is not uniform either. Humus forms through the decomposition of the remains of plants, animals and micro-organisms; products of their vital activity are often observed in humus. As they decompose organic remains lose their original shape and become darker or brown. Starch, cellulose and albumins are the first to decompose, woody fibre (lignite) resists decomposition longer. The mineral part of plant tissues is preserved in the humus together with the organic part.

Basically, humus consists of highly stable humic degradation matter. The type of humus evidently depends on the plants from which it forms. In the podsolic soils of the northern regions of the U.S.S.R. with their coniferous forests, the humus has a light hue and a high oxygen con-

tent It contains very little stable humic matter and a large quantity of other water soluble mobile substances

Ground water plays an important role in soil dissolving nutrient substances and thus allowing them to be absorbed by the roots of plants This water may be described as a solution of mineral and organic substances Where mineral matter predominates in the solution the soil is enriched with salts (for instance white alkali soils) where the solution contains a large quantity of organic matter peaty soils result sometimes there is only a small amount of salts and organic material as is often observed in sandy soils

Soil air has a different composition than the air of the atmosphere Complex reactions of the decomposition of organic matter take place in the soil increasing the carbon dioxide content and releasing gases not contained in the atmosphere Soil air has less oxygen than atmospheric air

Soils have a very diverse population largely consisting of microorganisms, of which there are tens of millions in one gram of soil The largest number of microorganisms is observed around the roots of plants

The composition of soils is constantly influenced by climatic factors and processes accompanying the development of plants Soils undergo very great changes as a result of man s activity in ploughing and fertilising it and also in cultivating it by various other methods

Geographical Distribution of Soils Soil is influenced most of all by climate and plants On the Earth s surface the climate changes from north to south the same change is observed as regards vegetation This phenomenon is responsible for a certain regularity in the change of soils

In general soils are distributed in belts according to the climatic zones (Fig 25)

The following main soils are distinguished 1) tundra, 2) podsolic 3) grey forest 4) chernozem 4) chestnut 6) brown soils of arid steppes 7) desert (grey or pale grey) 8) white alkali and saline and 9) lateritic

The climate of the Extreme North has a negative mean annual temperature At low temperatures the air is very humid and evaporation is therefore inconsiderable Annual precipitation is low—250 300 millimetres Owing to the negative mean annual temperatures there is a layer of

permafrost at a depth of about half a metre and sometimes less. This layer is impervious to water with the result that precipitation collects on the surface, bogging it up.

Of vegetation there are some varieties of moss (reindeer lichen), acid herbage (sedge, rush), small shrubs (cloudberry, blueberry, bearberry); dwarf birch and willow grow in the south of this belt. Some areas of the tundra are devoid of

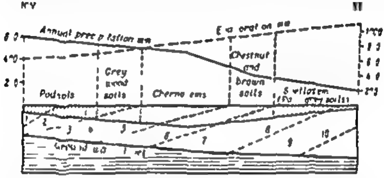

Fig. 2. Diagram showing the development of the soil forming process in the European part of the U.S.S.R. (after Zakharov)

1—washing away of humus; 2—accumulation of humus; 3—washing away of R_2O_3; 4—accumulation of R_2O_3; 5—leaching of $CaCO_3$; 6—leaching of $CaSO_4$; 7—accumulation of $CaCO_3$; 8—washing away of NaCl, Na_2SO_4; 9—accumulation of $CaSO_4$; 10—precipitation of soluble salts

soil. Because of the low temperatures in the tundra plants decompose very slowly, a factor which helps to build up turf beds. The conditions are unfavourable for organic life and the soils therefore contain very little humus. Meadow vegetation occurs only on the peaty soils of the river valleys. Forest vegetation is sometimes found on the tundra's southern boundary.

The climate is somewhat milder south of the tundra zone where mean annual temperatures are low but positive, the winters shorter and the summers warmer. The soil is thoroughly warmed; there is no permafrost. This is the forest belt.

Glacial moraine is the basic surface rock in this zone. Sand deposits, products of moraine washed by glacial streams, occur in low-lying areas. The annual precipitation is 600 millimetres, some of this water percolates deep into the soil

and into the rocks beneath it The basic vegetative cover consists of forests coniferous forests (taiga) in the north and mixed forests (coniferous and leaf bearing) in the south

A different kind of humus forms in the forest belt than in the tundra zone The reason for this is that the trunks needles and leaves contain resins and tanning matter which are absent in herbs These are acid substances with a small nitrogen and ash content Wood soil therefore has a different bacterial composition than tundra soil In geobotany the decomposition of forest organic matter is called fungus decomposition after the name of a group of lower plants which play an important role in this process Decomposition produces an acidic faintly coloured water soluble humus and the soil gets a yellow tint as various acids dissolve Thanks to the relatively high humidification alkalis and lime are washed out from soil and evacuated into deeper layers The upper soil layer lying at a depth of about 20 centimetres from the surface gets a most thorough washing When the soil profile is examined it can be seen that only the topmost layer contains some of humus which serves as a cementing material The layer beneath it, whose whitish hue gives it the appearance of ash, is called the podsolic layer It is a poor soil because nutrient substances are washed out of it Soil into which substances washed from overlying strata penetrate lies beneath the podsolic level These substances act as a cementing agent and also determine the colour and other features of this layer This soil is usually pale yellow on top and the entire layer is divided into small sharp edged polyhedrons (nuts) with depth the layer turns reddish brown and disintegrates into larger jointings, occasionally in the form of small blocks or pillars

Podsolic soil and sod are on the whole relatively poor but fertilisers make them as productive as chernozem

South of the forest belt stretches the steppe zone This new climatic and geobotanic zone has an even relief and a dry climate The long summer is hot the winter relatively short and the spring thaw sometimes begins as early as the end of February

Here the soil is thoroughly warmed and at the same time well aired, thanks to its *porosity* *with the result that plant* and animal remains decompose completely This produces

large quantities of water-soluble humus which combines with the iron and lime in the soil thus firmly consolidating in it. The humus-saturated soil forms a layer that sometimes reaches a depth of 100 centimetres. The abundance of humus gives the soil its black colour, hence the name *chernozem*.*

The quantity of humus in the soil of the steppe belt is not uniform everywhere. In areas adjoining forests the humus content is smaller than in the open steppe. The quantity of humus gradually decreases with depth and the soil acquires a light colour.

The intermediate belt of grey forest soil, representing a transition from chernozem to podsolic soil, usually lies between chernozem steppes and large tracts of forests with podsolic soil. A struggle goes on in this area between the forest and the steppe. This is due to the age-old fluctuations from moist to dry, which results in an alternation between forest and steppe vegetation. For example, in West Ukraine and west of the Urals the belts of forests alternate with belts of steppeland, hence the name—forest steppe. A transition from chernozem to podsolic soil or vice versa is observed in this area.

Grey forest soils form either naturally, when the struggle between the steppe and the forest takes place under natural conditions, i.e., without man's participation, or as a result of intervention by man who develops new lands, cuts down or burns out forests, tills the podsolic soil and fertilises it. The vegetative cover changes radically, the forests giving way to cereals and grasses.

Grey forest lands are more generous than podsolic soils, but they are not as fertile nor do they have such valuable physical properties as typical steppe chernozems.

To the south-east, steppe soils change into chestnut soils, this being due to a sharp change in the climate. The annual precipitation is below 250 millimetres, the summer is long and hot, and the winter is severe and relatively short. The soils here are inadequately saturated with moisture and the vegetable kingdom, therefore, also changes: the southern chernozem steppes with their abundance of feather-grass

* Derived from the words *chernaya zemlya*, which mean black earth. — *Tr.*

and sheep s fescue give way to fescue wormwood steppes and still further ~~south~~ to purely wormwood steppes Here the soil forming process is also different the soils being of a dark brown colour Below the chernozem zone the chestnut soils contain a slightly bigger quantity of humus and the colour changes from dark to light chestnut

These chestnut soils are nutrient rich and quite fertile But because of the low precipitation farming is possible only where the soil is artificially watered and other measures are taken to accumulate and preserve moisture in it

Chestnut soils gradually yield to *brown* soils the reason for this being that the climate is dryer and the temperature fluctuations cover a bigger range than in the preceding zone The soils are rich in soluble salts and contain very little humus

South of the brown soils lies a belt of desert with *grey* or *pale grey* soils The mean annual precipitation does not exceed 100 millimetres sometimes falling to as low as only a few millimetres Very considerable soil temperature fluctuations (from 85 C in summer to $-35°$ C in winter) are observed

In this belt the vegetative cover is not continuous developing mainly in early spring and withering towards the close of the same season Grey soils contain a large quantity of calcium carbonate and also soluble salts such as sodium chloride sodium sulphate and magnesium sulphate The abundance of lime and high ash substances and the low humic content make these soils infertile Drying up they break up into separate particles and are easily dispersed Various salts carried by capillary waters sometimes accumulate in low lying areas where ground waters are nearer the surface

Despite their native sterility grey soils are quite fertile when they are adequately watered They are cultivated in the Central Asian republics of the Soviet Union where skilful irrigation has turned separate desert areas into flowering oases

White alkali and *saline* soils form on soluble salt containing rocks in dry areas with a temperate warm or hot climate Due to the low humidity and intense evaporation capillary streams of ground water carry the water soluble

salts to the surface The more salt there is in the rock or in the ground water that moistens the rock the more intensively do the saline soils develop Frequently these soils form as a result of excessive watering due to unskilful irrigation

Lateritic soils (*terra rossa*) likewise form in areas with excessive humidity high temperatures and luxuriant vegetation The abundant precipitation and high temperature subject rocks to intensive weathering heighten the leaching process and accelerate the decomposition of plant and animal remains with the result that a considerable quantity of humus accumulates in the soil Lateritic soils are highly permeable to air and water and have a large moisture capacity They are very fertile providing fertilisers are used

Each soil mirrors the features of the natural conditions in which it was formed But the Earth s soil mantle is not stable The climate changes with the passage of centuries and this of course causes changes in the vegetation and consequently in the soils A cross section of abyssal rock will show how the natural conditions and the soils have gradually changed For example very rich coal deposits that could only have formed from luxuriant forests have been discovered on Spitsbergen which is one of the Earth s most rigorous regions with an extensive ice sheet This shows that in the remote past the climatic and geobotanic conditions on Spitsbergen were entirely different from what they are today

We have already said that man can influence the nature of the soil On vast territories man has adapted soils for farming subjecting them to considerable alterations This adaptation will no doubt continue and soils will become more fertile than ever

All rocks are subjected to weathering regardless of the conditions in which they formed As magma penetrates into the Earth s crust it cools down and forms deep seated rocks When these rocks come to the surface with its low pressure low and fluctuating temperatures air gases and moisture they adapt themselves to the new environment and metamorphose accordingly Under the action of weathering they form new mineral aggregations adjusted to the environment on the Earth s surface

Weathering creates a stable *waste mantle* which if the products of weathering had been stationary would have

completely enveloped the surface of continents However external forces set the Earth s outer shells of air and water in motion and these act upon the waste mantle breaking and shifting it and exposing the surface of rocks that had not been subjected to weathering *Denudation* or the exposure of rocks proceeds continuously in this manner

GEOLOGICAL ACTION OF THE WIND

The effective force of a wind depends on its velocity Even air moving at a rate of a few score centimetres per second can raise and transport fine dust A strong breeze can throw over and move rather large grains of up to several centimetres in diameter Gales and hurricanes whose velocity sometimes exceeds 50 metres per second are very destructive

Deflation and Corrasion The wind performs a definite geological function which naturally is not always and not everywhere manifested in equal measure There are regions where the action of the wind is particularly destructive these regions have poor or no vegetation at all and are called semi deserts and deserts or deflation regions Absence of vegetation, which fastens the soil by its roots gives free reign to the action of the wind In these regions the temperature changes (attaining a daily amplitude of up to 60° C and an annual amplitude of up to 100° C) causing intense mechanical weathering which supplies the material for deflation

The particles blown off the Earth s surface by the wind are transported over long distances depending on the size of the grains

Air currents blow not only in a horizontal plane along the Earth s surface but also in a vertical plane with the result that the particles torn from the soil are tossed high into the air Dust particles are raised to heights of hundreds of metres and sometimes as high as several kilometres fine sand is blown to a height of scores of metres and coarse sand up to eight or ten metres The material prepared by weathering is thus transported by the wind and is partially carried away from the region of deflation

Particles transported by the wind strike the obstacles in their path (rocks, boulders and various structures), grooving, scarring and even polishing and grinding them. This activity of the wind is called *corrasion*.

The windows on the weather side of buildings in deserts are sometimes polished to such a degree as to give the impression of having been frosted. This polishing is done by wind-borne sand. Ancient buildings that have survived in various places in Central Asia show the effects of corrasion. This is seen on the weather side of these buildings, particularly to a height of half a metre to a metre and a half and sometimes to three or four metres. The material formed by corrasion is picked up by the wind and transported farther. The removal of this loose material is called *deflation*. Corrasion and deflation are two inter-related processes engendering each other.

The intensity of corrasion is not the same everywhere and depends on the hardness of the rocks, the size of the grains and their arrangement in the rocks, the jointing, the bedding and other factors. Soft rocks wear away quickly, baring the hard rocks among them.

Wind-borne fragments are usually held in suspension at a height of a metre or a metre and a half above ground, and this accounts for the fact that maximum corrasion is observed at the base of cliffs. In deserts isolated boulders composed of horizontal beds are frequently battered into the shape of mushrooms or tables, while boulders consisting of steeply dipping beds are given the shape of needles, pillars, obelisks and so forth (Figs. 26-29).

Corrasion affects not only the foot of boulders and cliffs but also the horizontal surfaces, polishing them if they are hard and carving out yardangs or sharp-crested parallel ridges in soft rock. The bottom of the grooves between these ridges is often filled with sand (Fig. 30). Entire valleys have been formed by wind erosion. A frequent phenomenon in deserts, whirlwinds force sand into spiral motion to form vertical, conical or cylindrical hollows.

Corrasion also attacks lumps of rocks in the desert, the sand grinding them into characteristic trihedrons.

Where the hardness of vertical surfaces is not uniform, lunulets are carved out by the continuous bombardment by

F g 26 Weathering of sedimentary rocks n the v c nity of Kislovodsl

Fig 27 Witch s Tower Rock

sand These lunulets are widened and deepened by the sand to a size of tens of centimetres so that the rock surface looks like a honeycomb (Fig 31)

If a more or less horizontal seam in a rock series is softer than the others it yields to weathering deflation and corrasion much faster this may result in the formation of sizable cavities—caves These deflation caves occur in some of the valleys in the Caucasus and the Crimea where the sandstone beneath the hard Eocene limestone is eroded by the wind Some of the caves are so big that they are used as enclosures for livestock

Desert varnish" is another very interesting phenomenon of desert regions Nearly all rocks contain iron and manganese salts as well as moisture (the quantity may be

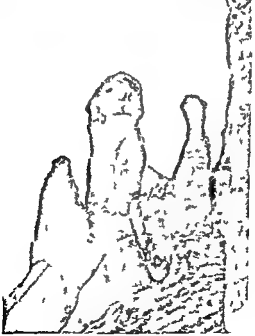

Fig 28 Pyramid rock formed by aeolian processes

very minute) The moisture on the side of the rock facing the sun evaporates intensively because of the heat and its place is taken by moisture from the deeper parts of the rock from where it brings with it dissolved iron and manganese Black iron and manganese salts accumulate in this way, giving the rock a black crust of a thickness of one or two millimetres This crust is harder than the rock itself and the polishing action of sand gives it a shiny lustre Desert varnish on south facing rocks is a typical feature of for example the desert and mountain regions of Central Asia

Fig 29 Weathering of igneous rocks

In regions with a temperate climate where almost the entire surface is covered by vegetation the conditions for deflation are much harder Grass shrubs and trees afford the soil surface excellent protection against deflation But in steppe regions it plays an important role For example dust or "black" storms have been observed in the south of the European part of the U S S R these storms occurred after a long spell of drought and deflated the soil sweeping a layer of chernozem (10 15 centimetres and over) from the fields Land reclamation in recent years has transformed this area making it almost completely safe against deflation Dust storms continue to be observed in North China South Mongolia Australia and elsewhere Sand storms called simooms which are a violent dust laden wind occasionally blow in Africa near vast sand deserts

Sorting and Deposition As we have mentioned above material borne by the wind from a deflation area is trans

ported over a certain distance which depends on the size of the material and the force of the wind and then deposited The smallest particles are frequently deposited several hundred kilometres away from the deflation area For example dust from the Kara Kum and Kizyl Kum deserts in Central Asia is transported eastward and deposited on the foothills of the Central Asian mountains Some authors are inclined to believe that this mode of dust deposition plays a very

Fig 30 Yardangs

important role in the formation of the surface mantle in foothill regions and thus explain the origin of loess rocks Like dust sand is transported by the wind but the distance it covers is much shorter—not more than a few score and very rarely a few hundred metres Larger rock fragments are rolled on the ground for short distances As they strike each other fragments of rock are ground and lose their original angular form

Wind borne masses of sand sometimes form more or less large mounds or heaps This is most frequently observed on the sea coast with its well defined sandy beaches Marine sand washed ashore by waves gradually dries and is blown by the wind For example on the Baltic Sea coast of the Soviet Union where westerly winds blow there are excellent beaches and the process by which sand is winnowed in an easterly direction is quite sharply defined The winnowed masses of sand form banks with a height from several to 200 metres and a base width of up to a kilometre Gradually drifting from the coast in an easterly direction the sands bury forests pastures orchards vegetable fields and even settlements These winnowed masses of sand are called *dunes*

Ripples are often observed on the dunes especially on their windward slopes As they drift a slanting lamination forms in them (Fig 32) The measures to halt the migration

Fig 31 Honeycomb weathering of Cretaceous sandstone the Crimea

of dunes include planting marram grass pines and other plants with a well developed horizontal root system on the windward slopes A soil mantle with vegetation forms on the sands after they are fixed There are fixed dunes in Sestroretsk and Ust Narovsk on the coast of the Gulf of Finland near Leningrad

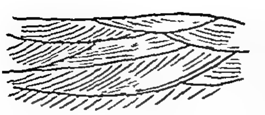

Fig. 32. Inverted bedding of sand dunes

The deflation and migration of sand with the formation of dunes is also observed on the banks of rivers flowing in a more or less meridional direction. Along these rivers the east bank usually slopes gently; during floods the river sand is deposited on the bank and when the water recedes the sand is exposed to the wind. The westerly and south westerly winds prevailing in the European part of the U.S.S.R. carry sand in an easterly and north easterly direction, greatly polluting the soil on windward slopes. This phenomenon is clearly observed on the banks of the Tsna, the Moksha, the Sura, the Volga, the Don and other rivers.

In sand deserts we distinguish sandhills, barkhans and barkhan chains. The topography depends on the initial relief, the quantity of sand, the climate and the force of the wind.

Isolated irregular mounds—sandhills—form in areas with shrubbery, little sand and changing winds.

Externally deflated sands sometimes have a uniquely regular outline. On the windward side the winnowed masses of sand have very gently (5-12°) sloping surfaces. The leeward sides are steep and have a 35° gradient angle that is characteristic of crumbling granular masses. These mounds have protruding edges due to the action of the wind. Seen *from above they resemble a half moon or a horseshoe* with gently sloping windward sides and steep lee sides. These mounds are called *barkhans* (Fig. 33) and are typical of desert and semi-desert regions.

If the winds blow alternately in different directions the barkhans are rearranged and their steep slopes gradually migrate leeward. For instance, in the season of westerly or south westerly winds all barkhans turn the ends of their crescents to the east, and in the season of easterly and north easterly winds they gradually rearrange themselves and turn to the west or south west.

Barkhans sometimes stand isolated from each other but in areas where several barkhans develop alongside one another, their edges merge and thus form barkhan chains The spaces between these chains (ridges) are depressions with patches of clay (takyrs)

In addition to barkhan chains extending perpendicularly to the direction of the wind there are long ramparts extending in the direction of the wind They fill the relief

Fig ? Solitary barkhan

with pits and ridges and where the wind blows in different directions they form immobile ramparts round deflation basins Pyramid shaped dunes form in areas intersected by winds at right angles

Some barkhans are 20 30 metres high Like dunes they can only be formed where there is an adequate supply of sand There are no barkhans in stone deserts and takyrs only small, barkhan like deflated masses of sands are found there Not higher than 20 30 centimetres they are small models of barkhans often of a very regular shape

Barkhans emerge when an obstacle a boulder or a bush stands in the path of a winnowed mass of sand The winnowing continues until the sand reaches the level of the obstacle (Fig 3a) Then sand is poured on the leeward side and tips of a crescent are built up by the wind on

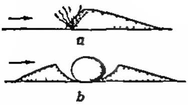

Fig 34 Formation of a hillock behind a shrub (a) and in front and behind a rock (b)

either side (Fig 35) Drifting mounds develop if the supply of sand is not sufficient to form barkhans Where the supply of sand is adequate barkhans grow merge together and form rows like dunes The gaps between the bark hans form chains of kettle holes (Fig 36) Such is the behaviour of the sands of the Kara Kum and Kizyl Kum deserts in Central Asia of Eastern Mongolia and the Tarim Basin of the Sahara Desert and of deserts in Arabia, Australia and other parts of the world

Some barkhans especially small ones drift rapidly in the direction of the prevailing winds Small barkhans usually travel 30 or 40 metres a year but in some cases *they can travel a distance of one or two hundred metres*

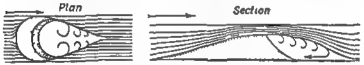

Fig 35 Diagram showing the direction and action of wind streams in the air current during the formation of barkhans

Ridgy sand advances at a much slower rate and buries sandless steppes cultivated fields and villages as has happened in Turkmenia Uzbekistan and Kazakhstan (Fig 37) Sands can be halted by planting vegetation

Barkhan sands occur chiefly on the margins of deserts rarely in the interior The bulk of wind borne sand and dust moves from the interior of deserts to their borders where the larger particles settle dust is transported past the boundaries of deserts to areas with vegetation and rainfall where after meeting winds blowing from other

Fig. 36. Barkhan field

Fig. 37. Vegetation buried by sand in the region of the Aral Sea

directions the desert winds lose their force and deposit this fine material. The layer of dust grows at a rate of one or two millimetres a year, but in the course of thousands of years it forms deposits whose thickness is from 15 to 20 metres and sometimes more.

This wind borne desert dust gradually accumulates and forms thick layers of yellow soil or *loess* (Fig. 38).

A classical example is China where loess covers huge expanses and is *deposited on different hypsometric surfaces*; the deposits are sometimes 400 metres thick. The Gobi, Khami and Jungar deserts are the "dust factory" for loess in North China.

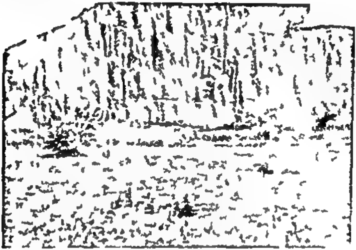

Fig. 38. Loess bluffs on the bank of the Shakhrikhan-Sai in the Fergana Valley

The conditions for eolation or the geological activity of winds are not uniform. The most favourable are in deserts—*equatorial deserts (Sahara, Arabia, Mexico and so on)*, northern deserts (Aral and Caspian), the deserts in China and Mongolia (Gobi) and other deserts.

Depending on natural conditions, deserts are divided into clayey deserts (takyrs), sandy deserts and stone deserts. Clayey deserts are flat plains, sandy deserts have a hummock and flat surface, and stone deserts are regions where the wind removes loose material leaving solid rocks bare to the continuous attack of the weather.

These three types of deserts are naturally linked up in space The landscape of stone deserts consists of regions of deflation which give way first to regions of accumula tion of eolian sediments (sandy dune barkhan land cape) and then to the marginal zones of deserts where silt and clayey material accumulate The general facies changes of continental deposits is reflected in this spatial change of eolian sediments

GEOLOGICAL ACTION OF FLOWING SURFACE WATER

Atmospheric precipitation as rain and snow and also water from springs move from elevated to lower areas performing a geological function on the way We distin guish the action of surface waters not gathered into regular channels (plane erosion or deluvial process) and the action of surface waters flowing in regular channels in streams and rivers (linear erosion or erosive process)

The deluvial process

Here water moves along the Earth s surface as down an inclined plane—the run off takes the form of a continuous water sheet in which separate streams interlace Under nat ural conditions such a water sheet forms on upland slopes and on the sides of ravines and river valleys

This sheet of water is only a few millimetres thick However as it streams down slopes over a long period water performs a noticeable function Its motive force is equal to half the product of its mass by the square of its velocity Therefore the steeper the slope and the more rain water that falls on it the greater is the motive force of the streams and consequently the stronger is their action This action consists in the run off picking up and transporting fine products of weathering and particles of soft rocks such as clays and marls of which the slopes are composed These particles move down the slope and drop into cavities

A slope sometimes descends evenly directly into a water channel in which case all the particles washed off the slope reach the channel where they are picked up and carried away But a slope usually flattens out at the bottom where the run off velocity drops with the result that coarse material is deposited If the water channel is sufficiently far from the foot of the slope the rain water may not reach it in which case all the water borne material is heaped up at the bottom of the slope The streams of surface water *that do not gather in regular channels gradually wash* particles of rocks away from the top of a slope and transport them to its bottom This is known as the deluvial process and the accumulated washed away particles are called *deluvium* Depending on the duration of this process the deluvium deposits sometimes grow to a thickness of several scores of metres

Deluvial deposits accumulate at the foot of slopes in the form of trains Morphologically the latter resemble talus trains The difference between them lies in the way debris is distributed In deluvium the coarse grained fraction remains on top of the slope while in talus it gathers at the bottom

If the slope consists of superimposed beds the topmost bed is eroded first then the second bed is exposed to weathering transported downhill and superimposed on the bed that had been brought down first The products of ablation of the third bed are arranged still higher in the deluvial series Thus in deluvial deposits we observe the same beds lying near the water divide in a rewashed state but arranged in inverse order

The composition of the material in deluvial deposits their colour thickness and other features depend on the height of slope its steepness and the hardness of the rocks The deluvial deposits on the sides of valleys composed of uniform clayey series are of the same clayey pattern but *only rewashed In areas composed of various rocks* the deluvial deposits are not uniform

Ablation is facilitated if the slope is steep and not fixed by vegetation Grass protects slopes against deluvial action because it bends in the direction in which the water flows and forms a protective coating There is intensive

ablation on ploughed slopes particularly before the sown vegetation germinates and strikes root Deluvial ablation is often a menace to farming because fertile soil is washed away

In the final analysis ablation does the job of flattening out any ruggedness in the relief the interfluvial areas sink gradually and the low areas rise at the expense of debris brought down to the foot of slopes

Erosion

If a hollow (rut or groove) appears on the side of a hill it collects many of the streams Erosion proceeds more intensively in this hollow than elsewhere The original hollow with its sharply defined outlines grows longer uphill until it reaches the crest of the slope It expands in the centre while the lower part flattens out as debris accumulates A gully thus takes shape on a once perfectly even slope Each section of a valley is subject to different geological action erosion in the upper transportation in the middle and depositation in the lower section The level at the foot of a slope from which a gully grows is called *the base level of erosion* This will be the level of the water basin (river, sea) into which the river flows

Systems of Gullies There sometimes arises a system of gullies running in more or less parallel directions from a watershed towards a valley and cutting into its slopes frequently to a considerable depth (up to several tens of metres) (Fig 39) Branches may appear in the principal gully and grow together with it i e, as they grow their apexes rise in the direction of the watershed and they become deeper and wider where they join the principal gully At the top of a gully there is usually a cliff from which rain water rushes down, undermining the base of the cliff and thus expanding the gully

The rate at which a system of gullies develops depends on the geological pattern of the slopes of a watershed and on their steepness Frequently a system of gullies gradually climbs to the top of a watershed cuts it and attacks the opposite slope As it develops a gully which has penetrated

into an adjacent drainage system may encounter the gullies of this slope cut into them and intercept the water carried by them Not only gully drainage but also the river drainage of the opposite slope can thus be intercepted This process is known as river valley piracy

Some gullies are very long and have a complex network of branches The growth of a gully can be easily traced

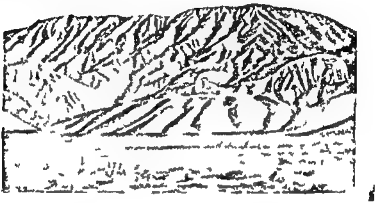

Fig 39 Development of a gully network due to the erosion of steep clayey slopes

Separate sections and occasionally fairly large areas of an interfluve can be cut up by a dense network of gullies and made inaccessible and unsuitable for cultivation

Gullies develop very rapidly in barren foothill areas composed of loess like rocks

Gullies usually carry water only in the rainy season or during the spring thaw and are dry in other seasons As they gradually grow wider and deeper they reach a stage where their beds (thalweg) become flat and erosion ceases The bed of a gully is at first quite steep and the water therefore has a very great velocity as the ravine lengthens out its gradient becomes gentler and this slows the water down and consequently its force decreases and the gullies stop growing

In a *temperate climate* the slopes and bed of a gully are covered with sod i e grass bushes and even trees grow on it These gullies are called ravines

When a deepening gully strikes a water saturated *stratum of rock springs* appear on its bed, giving rise to a continuously flowing stream By draining ground waters gullies lower their level and thereby cause enormous harm because of the unfavourable conditions they create for the development of vegetation The spread of gullies is combated primarily by planting bushes and trees in their upper reaches and also by constructing dams (Fig 40)

Fig 40 Stopping the spread of gullies with dams

The erosion that is observed in gullies takes place in rivers on a much bigger scale

River Systems The area over which a river flows emptying into a central channel is called a drainage basin The basins of big rivers occupy vast areas of hundreds of thousands of square kilometres The biggest drainage basin in the European part of the U S S R is that of the Volga which has an area of 1 380 000 square kilometres This basin unites the big Oka and Kama rivers and many thousands of small rivers and streams that drain into the Volga and its principal tributaries

The geological action of rivers consists mainly in eroding river beds and banks and transporting and depositing rock waste All these aspects of activity are often manifested simultaneously in one and the same area of a valley

However the most vigorous erosion is observed in the upper reaches of a river where the bed gradient is very

steep in the midchannel section geological action consists chiefly of scouring transportation and depositation and in the lower course—of transportation and depositation

Fig. 61 Bed erosion in the upper reaches of a mountain stream

The intensity of erosion transportation and depositation in one and the same section of a river may vary considerably in time depending on the quantity of water in the river The more water there is in a river the more

Fig 42 A waterfall erodes the bed of a river

intense is the erosion process Given the same quantity of water in a stream erosion depends on the rate of flow It has been established that if the rate of flow is doubled the water carrying capacity increases 64 times while if the rate of flow is tripled it increases 729 times

River Bed Erosion River bed erosion is manifested where the flow is sufficiently fast to allow suspended materials to be transported it is particularly intense where eddying currents prevail (Fig 41) For example near waterfalls and rapids the whirlpools in rivers carve out giant pot holes (Fig 42) The hard material carried by water, especially coarse sand and pebble is the main factor furthering the deepening and furrowing activity of water Clear water even if it flows rapidly cannot leave any noticeable trace on the surface of hard rocks

The rate and magnitude of erosion depend on the composition of the rocks of which the banks consist Banks consisting of loose rock such as sands, loam clay and coarse gravel with uncemented grains (pebbles and boulders) are eroded very rapidly (Fig 43) Water eats away the foot of banks particle by particle making a deep groove with the result

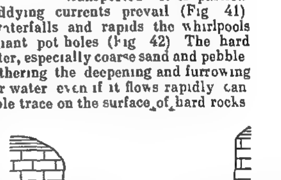

Fig 43 Cross section of a river valley
1—hard rock strata 2—soft rock strata 3—sediments carried by the river

that the overlying beds lose their support and big fragments collapse into the water, which erodes and carries them away

Banks consisting of sandstone schist limestone granite and other hard rocks resist erosion better Where rocks are hard the work of the water slows down considerably but in spite of this rivers cut into them inch by inch forming enormous canyons

Lateral Erosion *A river erodes its bed in a vertical* direction as long as its force is great enough to enable it to remove all demolished material from the original bed When a river loses its force it begins to deposit the material transported by it and erosion of the bed ceases

During floods a river erodes its banks thus steadily widening its valley This is noticeable particularly when a river overflows its banks

A river's highest water level is known as its flood or high water level (the lowest water level in a river is called the low or normal water level) During high water a river's level occasionally rises as much as several metres For instance in the Volga in the vicinity of the Zhiguli Hills flood waters rise 14 15 metres above the normal water level In the Moskva River flood waters have often overflown the banks in the low lying districts of Moscow and this made it necessary to build high embankments During floods a river receives from 30 to 100 times more water than usual In countries with a more uniform climate the quantity of water in rivers during floods is two or three times greater than during the low water season while in countries with a wet winter marked by abundant snow or rain the quantity of water increases 5 20 fold and sometimes even more than that

One can often see how turbulent streams of spring water erode banks over a distance of several kilometres and cover several metres of the forebank

Through lateral erosion rivers often carve twisting channels for themselves attacking now one and now the other bank *A river may swerve from its original course and* for various reasons start developing a bend In small streams such an accidental cause may be for example a sunken tree around which transported material accumu

lates, forcing the water to flow closer to the opposite bank. In large rivers a deviation may be caused by a landslide.

Fig. 44. A meander and the formation of an oxbow lake

A river's course is frequently changed by its tributaries, which evacuate material to their mouths and form alluvial fans in the shape of a peninsula or island between which they flow and branch out. If this material is abundant and the flood water cannot scour it, the river turns toward the opposite bank, eroding it and thereby forming a bend. The bends in a river channel gradually become sharper because the velocity of the water and, therefore, its eroding activity are always higher near the scooped-out bank along which the channel is the deepest; the material carried by a river is deposited forming alluvium (Fig. 44, 45) along the protruding bank, where the current is slower. The eroded bank slowly retreats and forms a loop.

Eroding each bank in turn, the river gradually widens its valley, and the region of lateral erosion can therefore also be called a valley-widening region.

During low water, a river flowing in some definite direction and eroding its concave bank more than the other builds up (on the convex bank) an embankment consisting of the material transported by it. This embankment subsequently determines the river's course. If during the next flood the river is unable to destroy the previous year's drifts, it will be forced to find a new channel and consequently change its course. The river may break through to a new channel by way of a bend; the remains of an old channel, which in low water have the shape of elongated crescent-shaped lakes, known as oxbow lakes, may, as a result, be seen in a river valley. During floods they may unite with the river's main channel.

During low water a river's channel is much narrower than its valley. In times of flood, water overflows the channel and inundates the entire valley from one slope to the other.

The flooded areas of a valley are called *flood plains*

One of the reasons a river deviates from its original course is the formation of *natural levees* They are formed when a river bursts its banks and overflows a grass and shrub overgrown flood plain the flow slows down and the transported mineral load is deposited along the margin

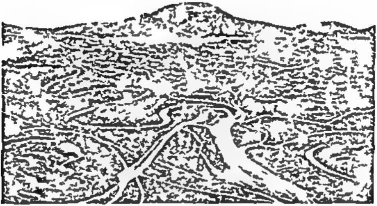

Fig. 40 Meanders of the Kuma River near Mineralnyye Vody

of the channel where it forms large embankments The sand and silt ridges built by the water grow with each flood Before a flood the water level in a channel protected by embankments is higher than the general level of the flood plain and oxbow lakes As the water rises during a flood it tends to flow over the embankments at the lowest point of the flood plain and develop a new channel or return to the old one The natural levee is eroded at the points where the water flows over it

Alluvial Process The work that a river does in depositing sediments is called the alluvial process while the deposited sediment is called alluvium According to

E V Shantser the alluvium in a river valley can be divided into three categories channel, flood plain and lake Flood plain alluvium everywhere overlies channel alluvium, because the latter covers the entire bed of the valley as a result of the displacement of the channel downstream (due to the absence of a concave bank—meanders) The alluvium deposited by rivers with a different rate of flow and eroding different rocks will obviously be different The alluvium of some rivers consists of coarse waste and of others—of fine sand clay or silt Sediment of different size may be transported and deposited even in various sections of the same river or at different times of the river's existence During floods when the force of the water is high a river transports coarse waste When a flood subsides the river begins to deposit the material it carries in suspension During the low water period therefore a river is nearly transparent in contrast to the time of spring floods when the water is very turbid

During a flood the quantity of material carried by a river greatly increases For example when the Hwang Ho in China overflows its banks it carries 400 times more sediment than during the low water period In the course of four rainy months the Ganges in India empties into the Indian Ocean 24 times more sediment than during the other eight months of the year A part of this material floats in the water i e it is carried in suspension the remainder is rolled along the river bed (drawn drift) When the water-level drops a river first deposits the drawn drift and then gradually the material carried in suspension This accounts for the sorting out of the deposited materials which depends on the changes in the water level and on a deceleration of the rate of flow Insofar as the separate streams in a river move irregularly forming whirlpools and flowing from one bank to another the alluvium is bedded haphazardly In profile an alluvial cone is usually stratified unevenly (Fig 46)

When the alluvial process is examined it should be borne in mind that the mechanical composition of the alluvium deposited by mountain streams differs from that of the alluvium laid down by flat land rivers As a rule the latter carry small particles of silt and sand mountain

rivers whose gradient is very steep at a definite stage of the formation of valleys transport gravel and pebbles in addition to silt and sand, and during floods they sometimes bring down rocks with a diameter of more than a metre As they are rolled along the bed of a river these rocks rub against each other are ground and polished acquire an

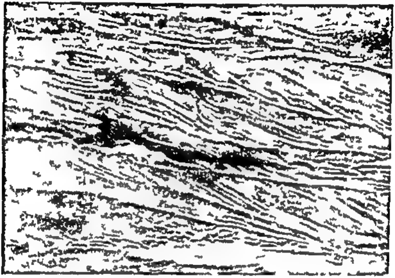

Fig 46 Oblique stratification of alluvium

ellipsoidal or spherical shape and are gradually worn down to pebble and then to sand Thus even big *mountain rivers laying down coarse material in their upper reaches gradually* begin to deposit ever finer grains Particles of clay and silt are sometimes transported as far as the point where a river discharges its waters into a lake or sea

Coarse waste may also be deposited in the lower reaches of a river For example during the spring ice drift ice floes may carry stones far downstream and deposit them where normally only silt and sand are deposited

Rivers carry enormous quantities of sediment to the sea The *Amu Darya* for example carries 44 854 000 cubic

metres of sediment a year to the Aral Sea the Hwang Ho in China transports nearly 900 000 000 cubic metres of sediment a year Even the Rion River with its relatively clear water carries 8,000,000 cubic metres of sediment a year to the Black Sea

Besides solid rock exposures, into which their valleys are cut, there are deposits of sediment—boulders, pebbles sand—in the channels of even swift mountain streams But this material only lies in the channels until the annual spring flood when all or a part of it is transported to a new place In the area where a valley widens out laterally the material borne by the river is deposited on the valley floor usually near a bulging bank

The principal area where sediment is deposited is in the lower section of a valley where the gradient is gentler, the current slow and the river is unable to erode its banks except during floods Most of the fine material is deposited here since the coarser material (gravel pebbles) had already been deposited in the middle and upper reaches of the river Rivers which do not unload sediment in their lower reaches carry it to the sea or lake and form a delta (Fig 47) A *delta* is a land area at the mouth of a river wrested from the sea and consisting of alluvium It usually has the shape of a triangle with the apex directed upstream In its delta a river often branches out separating into numerous twisting channels that change their position during a flood When a delta is inundated the level of the deposits in it gradually rises as new alluvium settles Rivers like the Volga the Neva (in whose delta Leningrad is situated) the Lena, the Danube and the Nile have very large deltas Some rivers have dry deltas with an area of hundreds of square kilometres for instance the Sokh the Murghab and the Zeravshan These rivers deposit clastic material as they leave mountains The deltas of these rivers consist of well rounded but coarse clastic material near mountains and of fine material along the edges

Many of the rivers emptying into seas and oceans have no deltas The river mouths located in the area of high tides as well as in the zone where the sea coast is gradually sinking have the shape of a narrow bay cutting deep

inland Such a bay is called an estuary or liman The Dnieper the Ob the Bug the Seine the Congo and the Amazon for example have estuaries

Stages of River Development From the source to the mouth the curve of a river's bed (longitudinal profile) which is steep in the upper reaches, gradually flattens

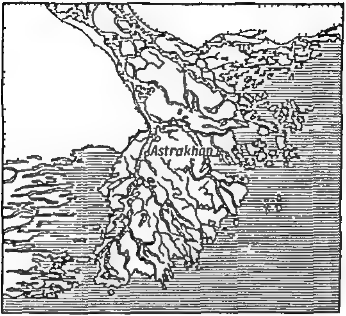

Fig 47 Delta of the Volga River

out as it is eroded by the flowing water and tends to become the extreme base level of erosion or the profile of equilibrium between erosion and accumulation in the river valley

In its course a river often encounters rocks of unequal hardness The harder rocks resist erosion better and rapids and waterfalls appear where they are exposed to the water (Fig 48) Each of these rapids and waterfalls is a local base level of erosion all sections of the river above this rift rapid or waterfall build up their profile with respect

to this new base level, while the river's main base level is in its lower course near the mouth. The same picture is observed when a river is artificially dammed.

After it has worked out its own profile of equilibrium it ceases to deepen its channel; bed erosion in the upper reaches gives place to lateral erosion, and the shape of the valley changes from a *V* to a *U*.

In the course of a river's activity its valley may become very wide and filled entirely with alluvium. In this period the flow loses its force and bed erosion ceases.

Fig. 48. Mountain waterfall

There are three stages in the development of a river: the youthful stage, when bed erosion prevails; the mature stage, when lateral erosion develops intensively; and lastly the old stage, when erosion stops. Very often separate sections of a river are in different stages of development: intensive erosion may be proceeding in the upper reaches at a time when at its mouth a river is already approaching the old stage.

A river drainage system with the accompanying changes in the relief of the basin occupied by this system may take many thousands of years to develop. As long as the river valleys are narrow and the spaces between them (interfluves) wide, the level of the greater part of the interfluves is higher than that of the river valleys. This is called the youthful relief stage. As development proceeds the interfluves grow narrower and the valleys become wider: the relief enters the mature stage. Lastly when all interfluves are cut off and only isolated hills (monadnocks) remain

the whole region shifts, as it were to a lower level, to the level of the river valleys this is the old stage of the relief Because of the very small surface gradients and the abundance of alluvial deposits water erosion comes almost to a standstill in this period river activity ceases and the region becomes almost a plain or *peneplain*

These successive stages of relief are called the geographical cycle To accomplish it a long period of geological time is required in the course of which the action of running water must not be disturbed by any local uplifts or subsidences of the Earth s crust This ideal development is rare The changes in the Earth s crust usually lead to changes in the gradients of various areas and in the flow regime of rivers

In the course of a drainage system s development some stages may be either accelerated or interrupted In the first case the drainage system begins to grow old prematurely In the second the drainage system is rejuvenated and the river begins to deepen its channel and widen the valley *These changes may be caused either by secular oscilla*

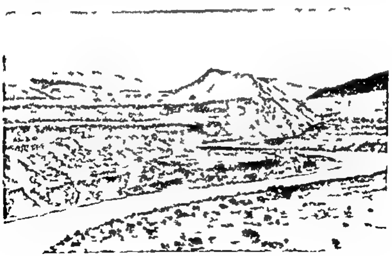

Fig 9 Terraces along the Sary Jas in the Tien Shan Mountains

tions of the Earth's crust or by substantial climatic fluctuations

If at a definite stage of a river system's development the base level of erosion gradually rises the river erosion curve will flatten out and, consequently the force of the river will decrease This leads to senility On the other

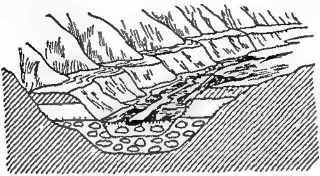

Fig 50 Cross section of river terraces

hand if the base level of erosion drops the region will begin a new geographical cycle the erosion curve will become steeper and cutting into the flood plain the river may begin actively to erode the alluvium it had previously deposited *A terrace overhanging the flood plain* thus begins to grow in place of a terrace that had been in the flood-plain The same will happen if the source area rises

Similarly if precipitation increases in a river basin the quantity of water in the river will also increase its force will become greater and erosion will intensify A system of bench like terraces stretching along the channel forms on both banks of a river if the base level repeatedly drops and the area containing the upper reaches rises (Figs 49 51) Terraces may consist of alluvium or of bed rocks They are called *rock* or *erosion terraces* Mixed terraces can also appear Alluvial terraces form when a river does not erode all the sediments it has deposited, mixed terraces arise when a river erodes all the alluvium in its bed and goes on to erode the basic channel Erosion

terraces only appear in the early stages of a river's development and are elongated ledges on the native slopes of valleys

A study of terraces will clarify the history of the development of river valleys and of land eroded by rivers

Flat country rivers usually have two or four terraces overhanging the flood plain Mountain rivers as a rule have as many as 18-30 terraces which rise above each other

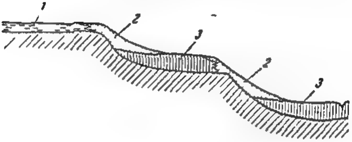

Fig 51 Diagram showing the arrangement of sediments on terraces
1—sediments of a watershed (eluvium) 2—sediments on slopes (deluvium) 3—sediments on a terrace (alluvium)

at intervals of tens and sometimes of hundreds of metres Because mountain slopes are very steep, the rivers coming down these slopes have a steeply dipping erosion curve and tremendous force The current in mountain streams is extremely turbulent and its destructive force is very great

The streams rising in highlands usually have waterfalls and carve out deep *canyons* (Fig 52) Above a waterfall a river usually flows between low banks and below it in deep canyons Tributaries that join a river in its lower stream likewise flow in deep and narrow gorges

Waterfalls are cross ledges of hard rock in the channel of a river There are many of them in mountain streams in the Caucasus Altai and Central Asia Very few occur in large flat country rivers The biggest waterfalls include Niagara Falls in North America (50 metres high) and the Victoria Falls on the Zambezi River in South Africa (133 metres high and nearly 1 600 metres wide) The erosive force

of falling water is very great and that is why deep pits (pot holes) are formed at the foot of a falls and the ledge from which the water drops is undermined with the result that the overhanging rock collapses and the waterfall itself is forced to retreat upstream (Niagara Falls, for instance recedes upstream at an annual rate of 0 915 metres) Below a waterfall the river flows through a deep canyon

Besides waterfalls rivers have rapids, which are large boulders or outcrops of hard bedrock covered by water only during floods

Torrents In mountain regions especially where the climate is very dry and hot small rivers and streams that are usually dry or have very little water may turn into powerful streams after heavy torrential rain and cause enormous damage Water pours down the steep mountain slopes at a great speed tearing away rock fragments and layers of loose soil

Semi melted jelly like masses of snow and ice mixed with mud fall from a great height slide along slopes rolling in front of them small crushed stones Water snow mud and

Fig 52 Canyon along the Terek River

Fig 53 Debris cone from a mountain valley It has the form of a terrace truncated by a river

Fig 54 Sediments brought by a mud and stone stream

sand mix together into a continuous dark sticky mass carrying spinning stones and boulders In this vast moving jumble huge blocks of stone buffet each other and collide with enormous force The air is rent by a thunderous roar which comes from the mountains as a danger warning

The destructive action of atmospheric water often leads to terrible disasters These sudden mud laden violent streams caused by heavy rain or by melting snow in highland regions are called torrents

Torrents carry to the mouth of their valleys enormous quantities of poorly rounded unsorted and unstratified rock waste called *proluvium* The deposits laid down by a swift-flowing stream form huge *alluvial fans* frequently called dry deltas (Figs 53 54) The cities of Alma Ata Andijan and Kokand in Central Asia and several towns in the Caucasus are situated on alluvial fans

Mud laden torrents are combated by planting trees on the slopes of river valleys building dams and so on

GEOLOGICAL ACTION OF UNDERGROUND WATERS

Rocks and Their Relation to Water The rocks of which the Earth s crust consists are not completely solid Each contains pores and cavities which act as receptacles for moisture called *underground water* to distinguish it from surface water The pores and cavities intercommunicate so that if there is a gradient or hydrostatic head the water can move in the rock from one cavity or pore to another

No two types of rock have the same capacity to let water through their pores Some for example pebbles gravel sand fissured granites and cavernous limestone have large pores and let water through quite easily while others—clay unfissured marl unfissured crystalline schists and hyaline rocks to name a few—have fine pores (micropores) and are almost impermeable to water

A rock s ability to absorb water is called its *permeability* According to their permeability all rocks are classified as a) permeable rocks b) semi permeable rocks or c) water tight or water resisting rocks

All pephitic uncemented sedimentary rocks such as pebbles gravel and sand as well as strongly fissured rocks belong to the permeable group Argillaceous sand loess peat and fissured marl can be considered as semi permeable rocks All hard unfissured crystalline rocks and also clay a clastic uncemented rock, belong to the water resisting group

Another important property of rocks is their ability to retain water

This property called *moisture capacity* is due to the capillary and hygroscopic structure of rocks according to which they can be divided into the following three categories

1 Rocks with a high moisture capacity (peat clay loam)

2 Rocks with a low moisture capacity (marl loess argillaceous sandstone argillaceous sand)

3 Rocks with no moisture capacity (igneous and solid sedimentary rocks including fissured and loose fragmental rocks such as gravel and pebbles)

A rock s moisture capacity depends on the size of the pores and cavities between its particles The finer the pores the greater is its moisture capacity and the lower its permeability The explanation for this is that the surface tension films forming in the capillary pores when a rock is saturated with water imprison the water particles already in the pores and at the same time prevent other water particles from penetrating through the rock to the underlying strata

As an illustration here are two examples

The voids between the pebbles in loose cobble round stone can hold a relatively large quantity of water but because of the free drainage almost all of it with the exception of a small quantity that moistens the surface of the pebble runs off into the underlying strata That is why shingle and other permeable rocks have a high water yield

A diametrically different picture is observed in clay when its capillary pores are saturated with water Dry clay with its high capillary porosity (up to 60 per cent) absorbs water rapidly and when it is saturated becomes impermeable because of the colloidal resistance offered to moving water by the surface tension films that form on the boundaries of the clayey stratum in the capillary pores That explains the low water yield of clay

Clay's high capillarity is due to the imbricated structure of its particles by virtue of which the pores between these particles are slit shaped This reduces the cross section of the pores and increases the area of contact with water

The following gives an idea of how great the moisture capacity of clay is it ranges from 40 to as high as 70 per cent which means that a cubic metre of clay can absorb and retain 0 2 0 4 cubic metre of water and sometimes even as much as 0 7 cubic metre

Origin of Ground Waters Ground waters originate in various ways One is through the *percolation* (*infiltration*) of rain or melting snow into the ground Ground waters may also accumulate through seepage from natural (lakes rivers) or artificial (canals storage lakes) bodies

In some areas however the presence of ground waters is not due to percolation For example ground water occurs at a depth of several metres and sometimes several scores of metres in deserts which have no precipitation throughout the summer and where evaporation is very high More often than not this water contains large quantities of minerals and is not suitable for drinking Barkhans frequently contain small quantities of fresh water It is believed that this fresh water owes its origin to the condensation of vaporous moisture some of which is always present in the atmosphere and in the air of the soil

Air can hold only a definite quantity of moisture This quantity depends on the temperature The higher the temperature of the air the greater is the quantity of vaporous moisture it can absorb At 0° C a fully saturated cubic metre of air contains up to 4 5 grams of vaporous moisture at 15 C it contains up to 12 7 grams and at 35 C up to 40 3 grams Usually air is somewhat undersaturated at 35 C desert air contains not more than half the normal 40 3 grams of vaporous moisture In other words undersaturation in deserts amounts to 20 grams i e the air has a relative humidity of 40 50 per cent On the other hand, because of the sharp difference between day and night temperatures desert air is oversaturated at night This surplus moisture is liberated in the form of dew that settles on the ground dampening and frequently, penetrating it Some water which saturates the soil and recharges

the ground waters is thus released as the air cools during the night. In deserts, therefore, ground waters originate through condensation of the vaporous moisture in the air. Consequently, *condensation* is another source of subsurface waters.

Volcanic eruptions are frequently accompanied by the ejection of water vapours. This has given scientists grounds for surmising that in addition to various gases the molten masses (magma) in the Earth contain water vapours. It has been suggested that because of their high temperature (hundreds of degrees), enormous pressure and saturation with gases the hot vapours in the Earth rapidly dissolve *mineral substances. They rise towards the upper layers* of the Earth's crust, dissolving mineral substances on the way. Upon reaching the cooler region of the Earth's crust these vapours turn to hot gas-saturated water. This water cools as it moves towards the surface, where quite often it is still very hot and contains a large quantity of mineral *impurities. This is called magmatic or young* water. Ground waters are to some extent recharged through the dehydration of the water-bearing minerals in the Earth's crust. Gypsum ($CaSO_4 \cdot 2H_2O$), for example, contains 21 per cent of water. This water is liberated when the gypsum enters the metamorphic zone and turns into anhydrite. Mirabilite ($Na_2SO_4 \cdot 10H_2O$) *contains 56 per cent water*. It is liberated when mirabilite is dehydrated.

Depending upon natural conditions, the underground waters in the different regions owe their origin to one or several of the above factors.

In practice, however, the water in even the deepest (two or three kilometres) artificial pits originated mainly through infiltration. The quantity of young water and also water from condensation and dehydration is evidently very inconsiderable.

Infiltration and condensation waters are very closely related to the moisture in the atmosphere and hydrosphere. These waters rotate constantly in one and the same cycle. As the water of oceans, seas and other reservoirs evaporates, it charges clouds where it condenses and then falls in the form of rain or snow. On the ground, where it forms streams and rivers fed by rain and melted snow and ice

this water flows to reservoirs The water lost by reservoirs is thus continuously restored, i e it goes through a definite cycle Some of the water falling on the Earth s surface evaporates, while another portion infiltrates into the ground, where through subterranean channels it likewise flows to reservoirs The latter portion of ground water represents the subterranean branch of the general drainage of atmospheric precipitation and is called *vadose* water to distinguish it from young water which is of magmatic origin

In some regions, owing to the climate 75 80 per cent of the annual precipitation is expended on the formation of surface and ground waters while in other regions the same amount is consumed by evaporation

Given the same or approximately the same climatic conditions the quantity of water absorbed through infiltration varies from 10 to 30 per cent on different soils with different gradients and vegetation

Moreover the quantity of rain and snow water that infiltrates into the ground depends on the permeability of the soil the type of vegetation the topography, the conditions under which rain and snow fall and under which snow melts the position of the gradients and the season In the mountain valleys of Central Asia for example up to 40 45 per cent of the spring and autumn precipitation infiltrates into the ground most of the winter precipitation feeds the surface run off, and the summer precipitation evaporates

Classification of Ground Waters The conditions under which ground waters occur in the Earth s crust and the quality of these waters are extraordinarily varied They are therefore classified by the conditions under which they occur and by their quality Let us examine ground waters as classified by the conditions under which they occur

The principal classifications are a) soil waters, b) subsoil waters and c) middle or interstratal waters

Soil waters occur at the Earth s surface They are influenced by the seasonal changes of climate in summer they are heated with the result that they evaporate intensively in the rainy season they saturate the soil turning it into mud and in winter they freeze

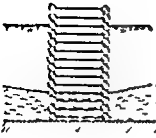

Fig. 50. Section of a well: 1—ground water table; 2—water-bearing stratum; 3—impermeable stratum

Their quality likewise undergoes sharp changes. In many arid regions the soil contains saline water; when the soil dries the salts crystallise and form an alkali flat or salt marsh. In regions with excessive humidity the soil waters contain an abundance of organic substances which give them their yellow-brown colour.

Subsoil waters occur at some distance below the surface. Beneath them they have what is called a water-resisting bed consisting of almost impermeable rocks. Most frequently these are clays, clay-like rocks, monolithic limestones, schists and other rocks (Fig. 50).

Thus, in contrast to soil waters, an indication of subsoil waters is that they have a water-resisting bed beneath them. Because of the more or less thick layer of waterless rock separating from them the Earth's surface, these waters do not have such a big amplitude of temperature changes as soil waters. Where subsoil waters occur at a depth of several metres (with the exception of the permafrost zone) they never freeze and their temperature does not show any considerable drop; on the other hand they are not heated so much in summer as soil waters. That is why subsoil waters seem to be cool in summer and warm in winter.

These waters differ greatly in quality as well. Some rocks contain very little soluble substances and the water in them is fresh and soft (the water in arenaceous deposits, for example). On the other extreme the subsoil waters are hard and brackish, and in deserts they are frequently salty. Brines, from which common salt is produced, form where ground waters percolate through rocks containing a large quantity of halite and other easily soluble salts.

The surface of subsoil waters is called the water table. The depth at which this water table occurs ranges from 0 to 20 metres and over, depending on the depth of the water-resisting layer and the thickness of the water-saturated (water-bearing) bed.

As we move from north to south we shall find a certain irregularity in the depth at which subsoil waters occur For example in regions with excessive humidity these waters lie very close to the surface there is an abundance of subsoil waters in these regions and it is fresh and contains a large quantity of organic substances Farther south the depth at which subsoil waters occur increases together with the mineral content in them

Subsoil waters are observed in the alluvial deposits of river valleys In these valleys they are undoubtedly fed by river water in addition to precipitation and the inflow of subsoil water from the slopes The quantity of these subsoil waters depends on the thickness and composition of the alluvial deposits There is generally very little subsoil water in the clay rich alluvial deposits of small rivers In the valleys of the Volga the Dnieper and other big rivers the alluvium is several tens of metres thick and consists of arenaceous deposits under these conditions there is an abundance of subsoil water This abundance is linked up with ancient glacial valleys consisting largely of quartz sand and embracing vast expanses One of these is the valley of the Yauza a tributary of the Moskva River The ancient alluvial deposits of this river have for decades been yielding nearly 4 000 000 buckets of fresh water a day for Moscow

The subsoil water level varies considerably and is governed by atmospheric conditions the precipitation regime the surface run off regime the vegetation, and other factors Water lying close to the surface is exposed to pollution Subsoil waters have no hydrostatic head with the result that when they are tapped they usually remain at their original depth

The surface contour of subsoil waters reproduces a smoothed variant of the Earth s surface relief and therefore where the water table slopes they form a stream In rare cases usually where the water resisting bed subsides there are sections with stagnant water these sections are called subsoil water basins

Subsoil water emerges to the surface in the form of gravity springs where the *water bearing bed is intersected* by a valley or truncated by the shore of a sea or lake The surface

of the underground flow descends gradually in the direction of the discharge and forms a *depression surface*

This surface may be inclined towards or away from the basin (Fig 56) *In the first case the surface waters are fed* by the ground waters and in the second—the ground waters are fed by the surface waters

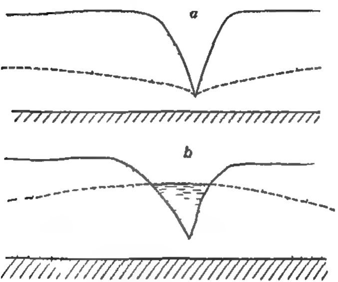

Fig 56 Depression surface
a) river fed by ground waters b) river fed ground waters

The relation between the level of sub oil water and that of the rivers mainly depends on the climate In a humid and temperate climate the rivers are fed by subsoil waters while in regions with a dry climate the reverse is observed i e the ubsoil waters are fed by rivers It must be noted that man greatly influences the relation between the level of subsoil and of surface waters

The difference between *middle (interstratal) waters* and subsoil waters is that they have a water resisting roof (con fining bed) above them This prevents the surface waters (rain snow and river water) from infiltrating down to the

level of the middle waters (Fig 57) Consequently, in contrast to ground waters whose alimentation region is usually located near by the alimentation region of middle waters may sometimes be hundreds of kilometres away

Interstratal aquifers may be tapped in a river valley or a deep ravine where water will flow in separate jets

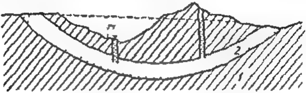

Fig 57 Diagram of artesian waters
1—water resisting bed 2—water bearing bed

(springs) or in a continuous stream (Fig 58) Here the underground water flows from the alimentation region to the river valley along the inclined surface of its water-resisting bed this is called descending water In so far as it is farther from the Earth s surface than ground water its temperature is more constant than the latter s In wells *reaching down to this water the annual temperature does not fluctuate more than* 1 2 C *The quality of interstratal descending water depends on the quantity of easily* soluble salts in the water bearing rock through which this water flows Interstratal waters may thus be soft hard or salty

Fig 58 Conditions under which springs appear in valleys

In some cases the interstratal aquifer has no direct discharge Water accu

mulates in it filling it up to the level of the confining bed and as a result develops a hydrostatic head The magnitude of the head depends on how much bigger the alimentation region of an aquifer is than the discharge area of the interstratal

Fig 59 A gushing artesian well

water If a well cuts through the confining bed and reaches the interstratal water the water in this well will rise as far as the hydrostatic head permits Where the surface topography is favourable the water will rise to the surface or even gush out

An artesian* well (Fig 59) is one where water rises by

* From Artesium (Artois) a region in the north of France where head waters were studied in detail for the first time

hydrostatic pre sure and an interstratal water level with a head is called an artesian water bearing bed A down warped stratification is the most favourable for the formation of artesian waters

The alimentation and propagation areas of interstratal waters form artesian basins There are many of these basins in the European part of the U S S R the most developed being the Moscow Dnieper Don and Black Sea basins

Many industrial and communal enterprises use artesian water which, coming from deep levels is free from bacteria and other organic pollution

A characteristic feature is that in all artesian basins deep seated aquifers contain the saltiest water For example, near Moscow water bearing beds in carboniferous deposits at a depth of 300 metres yield fresh artesian water Beds lying in Devonian deposits at a depth of 500 600 metres yield brackish water which is sometimes used as mineral water and beds occurring at a depth of 1,500 metres yield brine with a common salt content of 275 grams a litre

A number of factors govern the mineral content of underground waters and the change of this content with depth The first is that in its path water encounters various more or less easily soluble mineral masses the second is that the water s ability to dissolve minerals depends on the temperature the pre sure and also the content of gases and salts in it For example a litre of water containing no carbon dioxide can dissolve only a tenth of a gram of calcite If this same quantity of water is saturated with carbon dioxide it will dis olve a two or three times larger quantity of calcite Water saturated with carbon dioxide can therefore di solve quite a large quantity of limestone as it percolates through this rock However some of the calcite dissolved in water will be precipitated if the carbon dioxide evaporates

Hot Mineral Springs As we have already pointed out the temperature of underground waters depends on how deep they lie The temperature of ground waters occurring close to the Earth s surface undergoes seasonal changes The temperature of deep seated waters is more or less constant

Water with a temperature of up to 20° C is called cold of from 20 to 42° C warm and of over 42 C hot

Hot waters rise to the Earth s surface from great depths and most frequently occur near volcanic foci (active or extinct) Geysers hot springs which at regular or irregular intervals throw a jet of hot water and steam into the air are linked up with volcanic foci

However the high temperature of a spring is not always evidence of its association with magmatic chambers Waters of surface origin that reach deep levels and then rise to the surface again are frequently heated by the general increase of temperature with depth

The temperature of hot springs is constant and does not depend on the season But this temperature is not uniform at Goryachevodsk in the Caucasus the temperature of the hot springs is from 44 to 80 C at Pyatigorsk from 27 to 51° C at Zheleznovodsk 44 C and of the Arasan Spring in the Angren Basin (Tien Shan) 39 5 C

The depth of a spring opening can be calculated by the geothermal gradient Springs in which the water has a temperature of 80 C for example should rise from a depth of at least 3 500 metres The original temperature *of this water would probably be over 100 C because as* water rises to the surface it loses part of its heat to the cooler rocks around it

If mineralised water is evaporated in a porcelain cup it will leave a dense residue It is usually dried at a tem perature of 105 110 C and expressed in grams or milligrams of dense or dry residue per litre of water

Vernadsky suggested grouping waters as follows accord ing to their degree of mineralisation fresh water—up to a gram of den e residue per litre saline water—1 50 grams per litre and brine—over 50 grams per litre Fresh water is subdivided into hard (0 25-1 gram of den e residue per litre) and oft (le s than 0 25 gram of den e residue per litre) water

Ground Waters in the Permafrost Zon In perpetu ally frozen ground the temperature has been negative over a sustained period of many decades Permafrost occurs in regions with a ubzero mean annual temperature and is due to the fact that the bed rocks beneath it freeze in winter

and, with the exception of the upper part called the active layer, do not thaw out in summer

The occurrence of ground waters in the permafrost zone depends not so much on the composition of the rocks as on the degree to which these rocks are frozen permafrost layers are impermeable and this leads to a unique circulation of ground waters

N Tolstikhin has subdivided the ground waters of the permafrost zone into the following three categories 1) super permafrost, 2) interpermafrost and 3) infrapermafrost

Superpermafrost waters which are confined to the active layer can be regarded as ground waters They are recharged by precipitation, percolation of surface water and subfeeding from the deeper aquifers

These waters depend on seasonal freezing and melting Their mineral content is low but they contain a large quantity of organic material They cannot be recommended for drinking because organic substances decompose in them

Superpermafrost waters expand when they freeze and the resultant tremendous pressure forces compliant ground to bulge and form hydrolaccolith containing hummocks When these hummocks burst part of the water in them pours out and forms bodies of ice This deformation of the ground has to be taken into account during building

Interpermafrost and infrapermafrost waters do not freeze, this being due to the excellent permeability of the rocks the discharge of thermal water from lower lying levels and their location beneath rivers and lakes These waters have an unchanging regime and are pure and this makes them important as a source of supply for the Ussuri and Transbaikal railways

Movement of Ground Waters Ground waters generally move many times slower than surface waters, averaging 0 5 1 metre a day

Their rate of advance depends on the size of the pores in rocks (the rate of movement is faster through rocks with large pores) the hydraulic gradient of the carrier rocks the distance they travel and the temperature which governs their viscosity In poorly permeable rocks water takes months to travel a distance of a few hundred metres This explains why dry years affect the discharge of springs

Water with a temperature of up to 20° C is called cold of from 20 to 42° C warm and of over 42 C hot

Hot waters rise to the Earth s surface from great depths and most frequently occur near volcanic foci (active or extinct) Geysers hot springs which at regular or irregular intervals throw a jet of hot water and steam into the air are linked up with volcanic foci

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only after ten or twelve months Despite this slow rate of advance the waters perform a definite and sometimes very appreciable geological function as they percolate through rocks In this respect they may be regarded as a rock destroying and also a rock forming agent

The *destructive activity of ground waters (suffosion)* manifests itself in the dissolution of rocks mechanical erosion and evacuation of eroded particles

Unlike river water ground waters are strongly charged with mineral matter sometimes reaching the consistency of brine

The water solubility of minerals or rocks varies The minerals that dissolve easily (hundreds of grams per litre of water) include rock salt sodium carbonate and sodium sulphate That is why rock salt deposits only occur in areas where they are protected by impermeable beds (clays)

Gypsum and anhydrite are considered as medium soluble i e one part dissolves in 380 550 parts of water Limestone and dolomite do not dissolve readily at normal temperature and pressure it takes 1 000 3 000 parts of water to dissolve one part of limestone Quartz feldspar and mica are practically insoluble

Gases (carbon dioxide oxygen hydrogen sulphide methane and so on) likewise dissolve in water Water becomes enriched with carbon dioxide as it percolates through a humus rich vegetative layer The presence of carbon dioxide in water increases the solubility of limestone two or three times The organic substances in water act as reducing agents of various mineral compounds

Water containing oxygen carbon dioxide and inorganic and organic substances is thus a powerful geological factor which in the course of time no rock can resist

The entire range of geological phenomena linked up with the partial dissolution and erosion of rocks and the formation of sink holes in them is called *karst** and the areas where these phenomena develop are called karst regions Gypsum and limestone are exposed to intensive karst and leaching may proceed simultaneously from the

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* Named after the Karst limestone district of the Dinaric Alps near the Adriatic coast of Yugoslavia

surface and from within, where there are pores fissures tracks and so forth The surface of limestone is leached by jets of streaming rain or snow water which produces a series of more or less parallel furrows These furrows called swallow holes (Fig 60), are sometimes tens of centimetres deep

Fig 60 Swallow holes on limestone in a karst region

The water streaming down the surface of limestone finds a fissure in it penetrates into the rock through this fissure and carves out a kind of well or cave by dissolving the rock This well is approached through a funnel like hollow The water accumulating in this hollow called a sink hole streams into the well

As it moves in the limestone water dissolves the rock in its path hewing out sinks and channels thus giving rise to subterranean streams with tributaries Some of these streams break through to the surface where they give birth to karst springs Depending on the size of the alimentation area and on the precipitation some karst springs have a very high output Small mills and power

stations are sometimes built over them A single karst spring can be used to irrigate a land area of over a thousand hectares

Seasonal changes of the quantity of water in karst springs are observed where the alimentation area of a karst region is small After a thaw karst springs frequently yield large

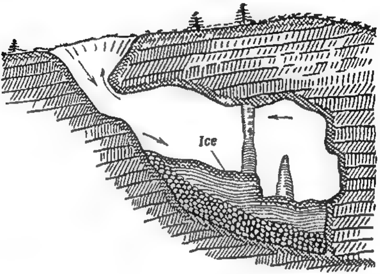

Fig 61 Diagram of a cave in which ice accumulates

quantities of water which decrease sharply if the summer is dry An example of this are the springs round Leningrad in spring they yield several millions of buckets of water, and in winter the yield drops to about 10 000 buckets

The largest karst caves in the Soviet Union are the Chatyr Dag caves in the Crimea the Barnukov Cave in Gorky Region the Kutaisi Caves in the Caucasus the Nizhne udinsk Cave in Siberia the Tuya Muyun Aravan Karama zar and Ugam caves in Central Asia and the Teshik Tash Cave near Termez

The 250 kilometre long Mammoth Cave in North America is the biggest karst cave in the world It consists of numer ous passages and galleries some of which are arranged in

several storeys the highest being 300 metres A river flows through the cave and there are several lakes

Some karst caves are more or less filled with ice (Fig 61) Ice fills caves that have gradually descending passages because of the cold air that accumulates in them In winter these caves freeze and then in spring vapour and water gets into them and also freeze But because cold air is heavier than warm air there is no exchange and the cold air remains stagnant

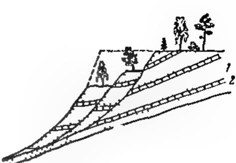

Fig 62 Section of a land lide
1—permeable beds — impermeable beds

There are ice filled caves near Kuibyshev The Kungur Cave in the Urals merits special attention It is the longest gypsum cave in the Soviet Union and the second longest in the world Located on the right bank of the Silva River near the town of Kungur it has more than a hundred grottoes and passages with a total length of 4 6 kilometres In it there are 36 lakes including 19 big ones The biggest has an area of 200 square metres The lakes are six metres deep, and the temperature of the water is 4 4 5 C

Karst processes are also observed in loess and loam and to distinguish them from karst processes in limestone and gypsum they are called clay or small karst They are very widespread in the Kopet-Dag Mountains

Landslides and rock avalanches along the sides of rivers lakes and seas where underground waters rise to the surface are another manifestation of suffosion

Landslides occur most frequently on slopes consisting of beds of permeable and impermeable rock (Fig 62) The surface of the impermeable bed is soaked and becomes slippery with the result that under the influence of various external factors the beds overlying it break away and slip down

Landslides may be caused by earthquakes heavy rains that increase the weight of the beds resting on an impermeable layer erosion of a slope by a river or sea and also by man s activity (inexpert watering of orchards and vegetable fields careless discharge of surplus water overloading by heavy structures and so forth) (Fig 63)

Landslides also occur among bedrocks when the following conditions obtain 1) layers and fissures sloping in the same direction as the valley 2) abundant ground water 3) an impermeable bed with permeable beds above it In argillaceous and arenaceous argillaceous rocks there may be landslides if the bedrocks are horizontal as well There may be landslides even if the rock strata have a reverse gradient dipping deep into a slope

Frequently landslides cause changes in the bedding of rocks twisting it and mixing rocks to form repetitions of the same strata on slopes

There have been cases of landslides carrying away large portions of a river bank several kilometres long and hundreds

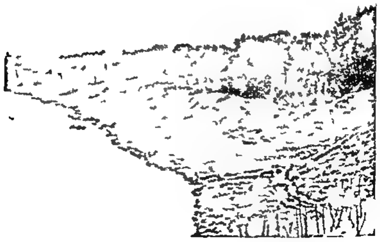

Fig 63 River bank landslide

of kilometres wide together with forests orchards and buildings The enormous damage caused by such landslides makes it necessary to take special measures

One of the principal ways of preventing landslides is to control surface waters drain underground waters and conduct earthwork correctly

Fig 64 Stalactites and stalagmites

Constructive Activity of Ground Waters Water becomes mineralised as it dissolves mineral masses It stops dissolving minerals only when it is saturated with mineral salts If it is oversaturated, it has to precipitate some of these salts Salts that are hard to dissolve are precipitated first

As water seeps through and dissolves limestone it forms calcium bicarbonate [$Ca(HCO_3)_2$] which when the solution evaporates and releases CO ■ readily precipitated as aragonite The conditions obtaining in karst caves stimulate the precipitation of calcium bicarbonate from solutions infiltrating into these caves That is why the water trickling down the walls of karst caves coats them with sinter and deposits mineral matter on the ceiling and the floor These column like deposits are called *stalactites* and *stalagmites* (Fig 64)

A stalactite is a deposit hanging from the ceiling of a cave and in appearance much resembling an icicle Drops of water percolate through a bed of limestone evaporate and leave behind the salt they had dissolved These drops usually trickle down the side of a node on the ceiling where the water dripping through the rock pores evaporates more intensively than elsewhere Grains of calcium carbonate and of calcite gradually accumulate in this way If the quantity of percolating water is large enough a part of the drops fall to the floor of the cave and also evaporate The deposit left by these drops grows upwards and is called a stalagmite Respectively growing from the ceiling and the floor the stalactites and stalagmites frequently join to form a pillar supporting the roof of the cave A karst cave can thus be filled and cemented The growth and fill ing up of a karst cave is a very long process There are caves completely filled with mineral material

Calcium carbonate which forms *tufa* (*travertine*) is frequently precipitated where water saturated with carbon dioxide breaks through to the surface Minerals may be deposited in fissures in rocks When that happens the fissures and voids between grains are filled with material matter calcite for example which cements the rock

Minerals may also be deposited when there is a drop in the temperature of the water which dissolved them Gas saturated water rising from a great depth where the tem perature is high precipitates some of the mineral matter in it when it reaches the cold upper layers This mineral matter fills and cements the fissures and pores in rocks

If the process by which water deposits salts goes on for a long time all voids become filled with cementing mineral matter In this way for example and turns into sandstone fissured rocks are welded and mineral veins form in fissures Hydrothermal deposits of ore (silver lead copper gold iron zinc lead and other metals) may form because the salts dissolved in water may include metallic salts

Siliceous sinter (*geyserite*) precipitated by water satu rated with silicic acid is a widespread mineral deposited by hot underground waters In addition to tufa and sili ceous inter spring waters precipitate large quantities of brown iron ore (limonite) for which there is a big demand

Mention must also be made of dendrites which are arborescent deposits of ferric and manganese oxides laid on stratification and cleavage planes

The water circulating in the Earth s crust thus transports various mineral compounds from one region to another thereby acting as an agent for the migration of mineral masses

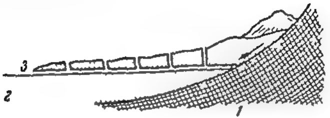

Fig 65 Section of a kariz

1—impermeable layers 2—permeable and water bearing beds 3—mouth

Practical Importance of Ground Waters A study of ground waters is of importance both to theory and practice From time immemorial these waters have been used for drinking and for irrigation This is borne out by the deep (100 metres and over) ancient wells along the caravan routes in Central Asia and also by karizes which are horizontal underground galleries carrying ground water by gravity flow (Fig 65)

Ground—thermal thermo mineral and thermo aerated—waters are of great balneological importance Where they contain adequate quantities of minerals they can be used as a raw material for the production of various salts

SNOW AND ICE AS GEOLOGICAL AGENTS

Snow and ice are linked up with definite climatic conditions A snow and ice cover can only form if there is abundant precipitation and if most of it falls in the form of snow To exist snow requires subzero temperatures and therefore it can only accumulate in crustal areas with a negative

The tremendous speed of snow avalanches starts a powerful cyclonic motion in the air which uproots trees, moves heaps of rocks and transports products of weathering. Frequently avalanches assume the proportions of calami-

Fig. 66. Firn on Mount Ai-Petri in winter

ties. In the Swiss Alps with its relatively dense population avalanches have taken a large toll of life. There have been destructive avalanches in the Caucasus and Pamirs as well (Fig. 67).

Avalanches are such a calamity that special observation posts have to be organised, barriers constructed in their path or measures taken to destroy them. There is a special avalanche forecasting service.

To give an idea of how frequently avalanches occur, we cite S. Kolesnik's figures for the Savoy Alps:

1903-04	648	1907-08	638
1904-05	517	1908-09	740
1905-06	672	1909-10	644
1906-07	787	1911-12	530

Year after year most avalanches roll down along regular channels.

Geological Activity of Ice

Types of Glaciers. Glaciers occur in polar regions where the snow line comes down to sea level or in high mountain regions remote from the poles. The area under glaciers is not constant, varying with changes in the climate. At present ten per cent of the Earth's land area is under glacier: 0.5 per cent of the glacier area is in high mountains and 99.5 per cent in the polar regions.

Glaciers differ in size and the position occupied by them depends on the relief, the elevation and the precipitation. Taking these factors into account, glaciers are classified into three principal types: 1) mountain (Alpine type), 2) highland (Scandinavian type) and 3) ice caps or continental glaciers (Greenland type). The first and second types occupy 98.5 per cent of the total area under glaciers.

Mountain glaciers are relatively small. They lie on the summit of mountains (stellate glaciers), occupy swallow holes on mountain slopes (corrie and hanging glaciers) or move down the floor of valleys (valley glaciers). Glaciers of this type occur in the Caucasus, the Tien Shan, the Pamirs, the Altai Mountains and the Alps (Fig. 68).

In the Caucasus modern glaciation occupies an area of 1,967 square kilometres; 1,465 square kilometres of this area are on the northern slope. According to data provided by S. Solovyov, the longest glaciers in the Caucasus are the Dykh Su (15.28 kilometres), the Karagum (14.94 kilometres), the Bezingi (13.61 kilometres), which lie on the

northern slope and the Lekzyr (13 65 kilometres), which lies on the southern slope In the Soviet Union the longest glaciers are in Central Asia Fedchenko Glacier in the Pamirs (77 kilometres) and Inylchek Glacier in the Tien Shan (80 kilometres) In Central Asia 11 000 square kilo metres are under glaciers

Fig 68 Devdorak Glacier Mount Kazbek

Highland glaciers form on mountains with flat summits which are covered by a solid sheet of ice There are many of these glaciers in the Scandinavian Mountains There is a certain similarity between these and cap glaciers on volcanic cones The latter are observed on mounts Elbrus (the Cauca sus) Kilimanjaro (Africa) and Klyuchevskaya (Kamchatka)

Continental glaciers occur in the polar regions where they occupy vast areas (in the Antarctic Greenland Spits bergen and other regions) Continental ice caps have a shield shaped surface and are somewhat elevated in the centre These glaciers are very thick In its centre the Greenland Glacier is at least 3 000 metres thick The ice fans out from the centre and descends to the sea as separate thick tongues The ice breaks as it enters the sea and comes to the surface in the form of icebergs

Formation of Glaciers In many cases, particularly in mountain glaciers, ice is transformed snow. As a great mass of snow accumulates it solidifies under its own pressure. Its surface melts in the sun during the day and freezes at night (even in summer). These alternating processes turn the snow into granular ice or *neve*.

Neve has a different structure than snow, each grain representing several accreted crystals of ice. These accreted crystals are small in the upper layers but become bigger with depth, reaching a size of 100 cubic millimetres at a depth of five or six metres.

Neve is also nourished by mountain hoarfrost or glazed frost precipitated on the windward slopes of mountain peaks. This hoarfrost forms in the following way. When humid air comes into contact with the frozen slopes it forms a solid one or two metres thick crust, which breaks away under its own weight and falls on the neve surface.

In some regions neve fields are nourished by snow avalanches born higher up in the mountains.

Near the surface neve frequently alternates with snow. Lower down the snow disappears and neve alternates with layers of solid ice.

Neve basins usually have a concave floor resembling a flat bowl. In them snow turns into neve as it solidifies and then into glacial ice which is essentially different from the ice that forms on the surface of water basins. The latter has a density of 0.917, glacial ice 0.909, and neve from 0.2 to 0.4.

Glaciers form through the accumulation of neve in the course of many centuries and possibly millenniums. Neve, whose lower portion has turned into glacial ice, overfills the corrie and because of its plasticity moves downhill. Glaciers descending along mountain valleys emerge in this way.

A névé basin is thus the alimentation area of a glacier. Masses of snow continuously accumulate in it and gradually turn into glacial ice. The body of a glacier ends in a tongue at the exit from the valley.

Movement of Glaciers Ice moves like a plastic substance. The rate of movement of a glacier is, in general, not high: from several tens of millimetres to several tens of centime-

Fig 69 Cross section of glacial valleys

1—exarated valley (n—shoulder) 2—valley after a glacier has moved through it twice (m—exarated terrace) 3—valley into which a river has cut its way

tres a day rarely reaching 1 15 metres a day Continental glaciers travel at a rate of up to 20 40 metres a day This rate of movement depends on the size of the ice mass and the gradient of the floor of the valley along which the glacier moves The rate of movement of a glacier can be determined by various methods The simplest is to place several large coloured stones across the glacial stream and to observe how they move downhill together with the glacier It has been established that the centre of a glacier moves at a higher rate than its margins

As a glacier moves down a valley it loses part of its ice through melting and evaporation The lower it descends the more ice is expended and a point can be reached where the amount of ice melting equals the supply from above A glacier cannot advance beyond such a point but masses of ice will continue to move

Glacial Activity * A glacier performs geological functions as it moves down a valley it abrades the floor of the valley by its own weight digs kettle holes with the boulders imprisoned in its bottom smooths out steep contours and gives the valley through which it moves the shape of a trough (Figs 69 70) The more rock waste a glacier carries and the faster is its rate of movement the more intensive its abrasive activity Granites and other hard rocks are polished and all protuberances on them are smoothed out On the other hand looser rocks are ploughed by glaciers hence the term glacial ploughing or exaration

The material that breaks away after it is ploughed up by a glacier or that has fallen from mountain slopes is trans

* The physical and geographical study of glaciers is the subject of a special science called glaciology

Fig 70 Descending tongues (medial moraines can be seen on the large glacier)

ported by the glacier and deposited either along its entire route or at its terminus

The rock debris carried and deposited by glaciers is called *moraine* There are different types of moraine *lower* located in the lower part of a glacier *lateral* located along the edges of a glacier and *internal* which is carried in the body of the glacier All these are moving types The debris

deposited by a glacial tongue where it melts after having been stationary for some time is called *terminal* moraine and the debris scattered in the ice near the glacier floor is called *ground* moraine (Fig 71)

Several glacial tongues frequently merge in the upper reaches of mountain valleys When this happens the largest

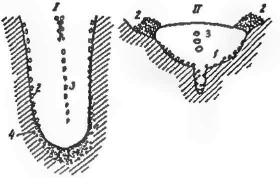

Fig 71 Top view (I) and section (II) of a glacier
1—ground moraine 2—lateral moraine 3—medial moraine 4—terminal moraine

becomes the principal tongue In some cases the principal glacier is so big and so deeply cut into the valley that the lateral glaciers superimpose themselves on it When confluent glaciers are approximately of the same size they merge along their sides The edges of each glacier carry lateral moraine which when the two glaciers merge likewise unite to form medial moraine

We can tell how many glaciers have united by the number of medial moraines plus one Thus if there are three parallel medial moraines on the surface of a glacier it shows that four glacial streams had merged

Terminal moraine releases its drift load which forms longitudinal and transversal ridges At the point where the glacier melts the surface internal and lower moraines form transversal ridges and the medial and lateral moraines longitudinal ridges A cup like depression often occupied by a lake forms between the ridge of terminal moraine and

the tip of the glacial tongue in the period when the glacier retreats When a glacier advances it shifts the terminal moraine farther down the valley, or, if the moraine ridge is very big moves over it

Externally, moraine is an unsorted mixture of various materials—clay sand rock debris pebbles and sometimes whole rock fragments (moraine loam and clay)

Many of the valleys through which glaciers move are tortuous and the floors may be flat or steep In its advance a glacier always hugs the convex side of the valley, with the result that that is where the most intensive ploughing takes place If there are rock obstacles on the floor of a

Fig 72 Ronski Glacier

valley the ice because it is brittle breaks into slabs which form crevasses running across the valley Depending on the steepness of the gradient and the thickness of the ice these crevasses may be very wide and deep Such sections are absolutely impassable (Fig 72) When a glacier reaches an area with a gentler gradient the crevasses close and the surface becomes smooth again

Fluvioglacial Deposits. Melting ice gives rise to streams which form a whole system of currents and jets beneath the body of the glacier.

A cave or grotto, sometimes a very big one, forms at the terminus of a glacier where these streams issue. When there is little water in these streams it is possible to walk quite far up the valley under the ice. But powerful streams frequently flow from under the ice, particularly in the latter half of the summer. As the temperature of the air drops, the melting process slackens, the streams become shallow and then disappear completely as winter approaches.

Glacial rills or fluvioglacial streams, as they are called, erode the moraines and, at the same time, sort out the morainal material. During the warm period of the year these streams reach the height of their power, their eroding activity proceeds very intensively and they carry quite large debris. In the lower reaches where the valley's gradient decreases the glacial rills slow down, their force decreases and they begin to deposit the coarse-grained material they had captured while eroding the moraine, and the fine-grained material is carried farther. Glacial streams form what are called aqueoglacial or fluvioglacial deposits. The material of which these deposits consist is sorted and stratified. Quite often fluvioglacial deposits are located between two moraines—of the previous and subsequent glaciation.

Fluvioglacial deposits may consist of gravel, sand, loam and clay. The large areas consisting of beds of sand and clay deposited by streams in front of a glacier are called *outwash plains*.

In closed basins (glacial lakes) the melt water from glaciers leaves deposits consisting of thin alternating strata of sand and clay. This texture is due to the seasonal accumulation of these sediments: the sand strata are deposited in spring and summer, and the clay strata in winter when the water level is low. These deposits are called *varved clays* and are 0.5-5 centimetres thick.

Glacial topography forms as a result of the melting and retreat of glaciers. The most typical are *eskers*. They are long narrow ridges arranged one behind the other or broad

flat elevations Along their sides they usually have peat filled ditches The eskers themselves consist of gravel and sand lying in distinct diagonal beds which is proof that they were deposited by running water

There are numerous eskers in Finland and Sweden where they are disposed in ridges running parallel to the glacial grooves Lateral eskers frequently merge with the main esker to form a system resembling that of a river with tributaries Eskers are 45 50 metres high The crests of some are so narrow that there is hardly room for a footpath

Advance and Retreat of Glaciers A study of mountain glaciers has revealed that their margins are unstable They advance and retreat in conformity with the periodic changes in the climate If the climate grows warmer ice wastage may exceed the supply and the glacier begins to grow shorter i e to retreat The reverse happens in a wet and cold period Observations conducted during a relatively short period showed that this retreat and advance is inconsiderable but in the course of decades this movement covers a distance of hundreds and even thousands of metres

Changes in the ice mass of a neve basin resulting from changes in the quantity of precipitation affect the entire ice field The climatic conditions in the region where the glacier descends likewise play an important role because in many cases the glacial tongue is several thousand metres below the neve field Therefore given stable conditions in the neve basin the glacier will retreat if ice melts intensively in the lower reaches of the valley

Moreover changes in the ice mass depend on the form and size of the alimentation area The position of the glacial tongue in relation to solar heating is important A tongue situated in a shady area is more stable than a tongue exposed to sunlight A mantle of rock material also protects a glacier from excessive melting and evaporation

Prehistoric Glaciation A study of the history of the Earth s crust shows that there have been epochs when glaciation embraced enormous areas Such glaciation occured in the Proterozoic era the Carboniferous and Permian periods and lastly the Quaternary period In the latter period a solid sheet of ice covered the whole of Northern and Eastern Europe in Moscow Region it was more than

a kilometre thick and its southern boundary passed south of Kiev

Scandinavia in whose mountains glaciers exist to this day was the centre of the Quaternary glaciation in Northern Europe It has been calculated that a 5 C drop in the mean annual temperature would be sufficient to cause these

Fig 73 Boulder left stranded by a glacier

glaciers to grow and occupy the whole of Northern and Central Europe The Quaternary glaciation has left distinct traces in a vast area in Europe A well defined morainal topography consisting of ridges of terminal moraines striated boulders (erratics) sheep back rocks, eskers and lakes can be seen in the Kola Peninsula and Finland These are clear indications of recent glaciation Farther south around Leningrad Kalinin Vologda and Pskov glaciation has left traces in the form of rounded striated boulders some of which weigh more than a ton (Fig 73) Quaternary moraine deposits in the European part of the U S S R and in the adjoining countries show how far south the continental ice had moved

The alternation of glacial and interglacial periods was due to climatic changes caused by deviations in insolation

as a result of the regime of solar heat radiation a shift in the angle of the Earth's axis and other factors

Some scientists are inclined to link climatic changes and the rise of glaciation with the processes taking place in the Earth itself Arrhenius, for instance considered that climatic changes may depend on fluctuations of the quantity of carbon dioxide in the atmosphere He believed that if the quantity of carbon dioxide were halved the Earth's temperature would fall by an average of 4 5 C, with the result that given sufficient precipitation the whole of Europe would be covered by a thick sheet of ice

Moreover it is considered that volcanic eruptions play a very important role in the rise of glaciers If the quantity of volcanic ash ejected into the air during intensive volcanic activity is large enough it may influence solar radiation and cause the Earth to cool

The Russian geographer Brounov advanced the opinion that glaciation requires not only a low temperature but also a change in the humidity regime of the air In Eastern Siberia where the cold pole passes in the vicinity of Verkhoyansk colder temperatures are registered than in Greenland But Greenland receives a larger quantity of precipitation and therefore has the necessary conditions for the accumulation of ice masses In Verkhoyansk on the other hand there is very little precipitation and no permanent snow cover ever forms

Epeirogenic uplifts (a 1 C drop in temperature per approximately 200 metres of elevation) are another factor stimulating glaciation Sea currents also influence the climate For example because of the Gulf Stream the port of Murmansk is ice free all year round while the port of Leningrad which is 600 kilometres farther south is ice bound for five months every year

We can thus see that glaciation depends not on one but on numerous factors

GEOLOGICAL ACTIVITY OF THE SEA

The geological activity of the sea follows the same pattern as that of rivers ice and the wind erosion transportation grinding sorting and deposition There are however a

number of features in the sea's activity that make it especially important to life on Earth

While the wind, surface waters and ice transport the material eroded by them down to sea level the sea hides this material beneath its waters. Its action is directed at wearing all continents and islands down to its own level

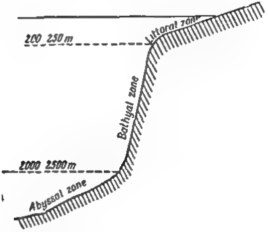

Fig 74 Diagram of the vertical zones of a sea floor

hence the name *abrasion*. This abrasive activity is observed along the shore line of all continents and islands whose total length is about 200 000 kilometres. Abrasion by the sea is clearly defined in many large land areas. A classical example is Heligoland, an island in the North Sea whose area was reduced from 920 to 1.5 square kilometres in 900 years

Organic rocks, of which there are relatively little in continental deposits, play an important role among marine sediments. The accumulation of marine sediments follows a clearly defined zonal pattern which depends on the bottom relief, the shore line and other factors

The sea floor descends not gradually but in steps (Fig 74). The first step is called the shelf or shallow water and

stretches to a depth of 200 metres In some places it is 400 000 kilometres wide and embraces 8 4 per cent of the surface of seas and oceans Part of the foreshore lies between high and low tide levels and is called the *littoral* Beyond the border of the littoral is the *pelagic zone*

The shelf gives way to the deep water or bathyal zone which is from 200 to 2 500 metres deep The sediments of the upper or shallower sections of the bathyal zone can be set in motion only by heavy seas or by deep sea currents

Terrigenous deposits (deposits derived from the land) do not reach the abyssal zone which extends below a depth of 2 500 3 000 metres Only volcanic ash and cosmic dust are carried to this zone

Destructive Activity of the Sea This activity stems from the work of wind waves tides and currents

Wind waves erode shores by their own pressure developed by the surf which breaks against beaches and also by the battering action of rock waste which they carry in suspension

This rock waste intensifies the action of waves because the stones of varying size the sand and other material hurled against cliffs by waves act as powerful corrasion agents

The most energetic geological activity by the sea is observed in the coastal zone

The force of the surf is very considerable and the pressure developed by water against the shore exceeds two or three kilograms per square centimetre along a rocky and precipitous coast if the waters in the littoral zone are deep Breakers that throw masses of water and rock debris to great heights are possible in such an area There have been cases of breaker hurled pebbles breaking the glass of lighthouse searchlights at a height of more than 20 metres above sea level If there is an in shore shoal (beach) the breakers lose much of their striking force through friction against the sea floor The force of waves decreases also with depth Their effective activity therefore is confined to a relatively small depth In the open sea ripples can be seen on water up to 200 metres deep

Waves develop their greatest force where they pound a precipitous coast Near the coastal city of Gagra in the

Fig 77 A wave-cut terrace

along coastlines exposed to tides while where wind waves alone are active there are only one notch and one terrace

The work done by tidal waters is particularly noticeable in narrow straits, bays and mouths of rivers they carve out canyons on the floor of straits and bays while in the mouths of rivers they hinder the formation of delta islands that turn these mouths into estuaries

Sea currents are likewise very destructive For example the Gulf Stream which is several hundred metres deep and 275 kilometres wide along the shores of Scandinavia washes away all the fine terrigenous sediments from the floor of the shallow water and from the upper parts of the continental slope and transports them over a distance of thousands of kilometres

Wind waves transport bottom sediments along the normal to the shore and also along the shore Sediments transported along the normal to the shore are thrown on the shore when oncoming waves predominate over ebb waves when there is an equilibrium between these waves the same quantity of material is transported shorewards as is carried away into the sea and when ebb waves predominate over oncoming waves sediments are transported seaward If the breaking waves are oblique in relation to the shore line sediments are transportd along the shore (Fig 80)

Coarse material is sorted at the same time that it is transported by waves The coarsest material is left near the shore smaller material carried farther away and lastly the finest particles of clay transported the farthest Benthonic material lying at depths of more than eight or ten metres can only be moved by violent storms

Shores are protected against the erosive activity of the sea with embankments consisting of concrete slabs and also with offshore concrete bars against which waves break without reaching the shore

F g 78 Elephant Trunk Rock Lake Baikal

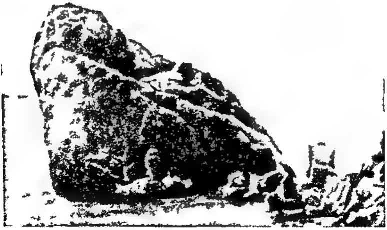

Fig 79 Wonder Rock the Crimea

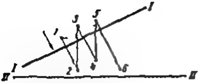

Fig 80 Diagram of the movement of pebbles along a sea shore The arrow shows the wind direction

I I—transversal wave crest *II II*—shoreline *1 2 3 4 5 6*—path of pebbles

Useful Activity of the Sea Not all the activity of the sea is destructive Eroded material is deposited along the coast and also over the entire shallow water area

The in wash of coarse material on gently sloping shores frequently leads to the formation of *off shore bars* (Fig 81) The material carried by waves to these shores is not washed away These sediments grow to form a bar 10-12 metres wide Sometimes several bars are formed parallel to each other the farthermost from the sea being built during violent storms and the nearest by weak waves

Sediments are deposited on the sea floor as well These are classified as littoral shallow water and abyssal sediments

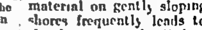

Fig 81 Off shore bar

In the littoral zone the sediments are continuously buffeted by waves which roll and sort them In the immediate vicinity of the shore the debris is poorly rolled and coarse and often consists of rock lumps and waste Farther away from the shore the sea deposits pebbles then gravel and sand which becomes finer with distance from the shore (Fig 82) In the littoral zone the waste lies in inclined beds Small particles with a diameter of less than 0 1 millimetre are not deposited near the shore but are carried in suspension and precipitated on the sea floor at depths from 20 to 200 metres i e in the shelf zone

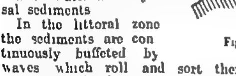

Fig 82 Distribution of terrigenous sediments in the sea

1—pebbles *2*—gravel and large grained sand *3*—medium grained sand *4*—fine sand *5*—clayey sand *6*—clay

Shelf deposits consist of sand clay and sometimes ooze There is always organic material in these deposits Marine vegetation grows abundantly in the shelf zone, and this makes for a favourable environment for marine life The sediments in this zone are usually clearly stratified oblique or irregular stratification is hardly ever observed The exceptions are the slopes of coral reefs which dip steeply into the sea with the result that sedimentation proceeds irregularly Traces of ripples which may be described as negative prints of waves can be seen in the shallowest regions of the littoral zone These prints are variously shaped but in contrast to similar wind and river formations they are always symmetrical

On the shelf a broad strip of sediments stretches along continents and islands The width of this strip averages 250 kilometres, and where rivers carrying large quantities of waste empty into the sea it broadens out to 600 kilometres Where the shelf is narrow terrigenous mud is also deposited on the continental shelf, provided it is not carried away by currents The belt of shelf deposits ends abruptly where there are strong currents

Organic and chemical sediments are deposited in the shelf zone in addition to sediments of purely continental (terrigenous) origin

The sediments deposited beyond the shallow water zone in the bathyal and particularly, the abyssal region are chiefly of organic origin the mineral admixture in these sediments is insignificant The material for organic sediments is supplied by the big and varied population of the sea

On the sea floor there are diverse algae sea lilies sponges bryozoans corals (in warm waters) mollusks echinoids and so forth

Reef building coral colonies play an important role in the formation of organic sediments Coral and algae thrive in shallow (not more than 20 45 metres) and warm sea water of normal salinity Coral reefs form right along the coast of continents and islands and also at considerable distances away from them in the region of the shallow sea

These reefs cease to grow during secular uplifts and when the sea floor gradually sinks only the lower part of the

reefs dies off Waves erode the dead portions of the reefs turning them into calcareous sand and finer calcareous silt

Some algae consume lime from sea water and deposit it in their stalks Beds of limestone may form from the remains of such stalks Shell limestone which is widespread in ancient deposits forms from the remains of mollusk shells In abyssal regions plankton remains turn into organic ooze

Sediments of chemical or biochemical origin accumulate in some areas These include calcareous and siliceous sediments rising from the redepositation of lime and silica from the skeletal remains of organisms Chemical sediments play a small role in the open ocean They accumulate mainly in coastal waters separated from the ocean by barrier beaches (marshy lakes at the mouth of rivers lagoons, bays and so on) through an increase in the salt concentration This phenomenon is observed in areas with an arid climate, the Kara Bogaz Gol on the east coast of the Caspian, for example

Material ejected by volcanoes (ejectamenta) plays some role in the accumulation of marine sediments particularly in abyssal regions where hardly any terrigenous particles occur Lastly there are cosmic dust and meteorites that fall into oceans

Beyond the belt of shelf sediments lies the zone of bathyal sediments represented by fine terrigenous material—blue red and green mud

Blue mud occurs over large areas of the ocean floor particularly in the Atlantic Sometimes it occurs in the shelf region as well In the Bay of Naples for example it is found at a depth of 15 metres This mud was brought to the surface from a maximum depth of 5 120 metres Owing to an admixture of ferric oxide the topmost layers usually have a red or brown tint but the rest of it is blue Ninety even per cent of this mud consists of particles of clay The carbonate content in it sometimes increases at the expense of the clay particles The quantity of quartz grains is very small Taken out of the water blue mud smells of hydrogen sulphide formed through the decomposition of organic matter The hydrogen sulphide and iron in the mud give

rise to ferrous sulphide, which is sometimes precipitated in the form of pyrite crystals or grains

Red mud occupies an area equal to one per cent of the area under blue mud It occurs opposite the mouth of the Amazon in the Atlantic and opposite the mouth of the Yangtze in the Pacific Its development is due, evidently, to the lateritic soil washed away by these rivers It gets its red hue from the ferric oxide in it Its composition varies greatly but normally it contains a somewhat smaller quantity of clay particles (up to 70 per cent) than blue mud and there have been cases where as much as 60 per cent of it has been found to consist of carbonates It always contains a small quantity of quartz Like blue mud it contains the remains of marine organisms

Green mud or sand occurs in the highest sections of the bathyal zone at a depth of 180 2 300 metres It owes its green colour to glauconite which forms with the participation of organic substances released by the decomposition of organisms Green mud contains a considerably smaller quantity of clay particles than either red or blue mud—usually not more than 48 per cent On the other hand the content of lime is rather large sometimes more than 50 60 per cent Glauconite sediments have formed in all periods of the Earth s life but they occur most frequently in Cretaceous and post Cretaceous deposits

Volcanic sand and *mud* are found around volcanic islands and coastal regions with volcanic activity Material ejected by volcanoes mixes with bottom sediments and consequently is regarded as a polluting element in basic sediments

Coral sand and *mud* occur in regions with developed coral structures which are either islands or barrier reefs stretching for a long distance along the coast of continents as for example the Great Barrier Reef off the east coast of Australia Sediments of this kind are particularly abundant on the floor of the tropical part of the Pacific Coral mud consists mainly of calcareous material and contains an insignificant quantity of clay particles

In the abyssal zone sediments form chiefly through the accumulation of organic matter the mineral impurities in these sediments are volcanic ash and cosmic dust Ooze takes

its name from the marine organisms predominant in it viz foraminiferal pteropod coccolithic diatomaceous and radiolarian ooze

Red abyssal mud occurs in deep parts (4 800 5 200 metres) of the ocean Unlike the red mud of the bathyal zone it occupies huge expanses which together are almost four times bigger than the area occupied by blue mud The colour of this mud varies from bright red to chocolate and in some areas it has blue shades It is delicate and plastic when wet and hard and brittle when dry It originates from the decomposition of volcanic ash which may contain a small quantity of terrigenous dust and the insoluble remains of shells of foraminifera and other plankton In some parts of the ocean the siliceous skeletal remains of radiolarians and diatoms also play an essential part in the composition of abyssal mud manganese nodules likewise occur here and there

Marine sediments are heterogenous over large areas The bedding and lithological composition of these sediments and also the quantity of organic impurities in them depend on depth the presence of currents the distance from the shore the salinity of the water and other factors Along rocky shores for example the sediments consist chiefly of large rock fragments Seaward these fragments give way to more or less well rounded pebbles and then to deposits of sand in which quartz grains predominate Still farther away the sand deposits are replaced by sediments of clay and silt

Each of these sediments has its own lithological character or *facies* The distribution of facies as described above is a feature of marine deposits But because of the epeirogenic movements on the surface of the land mass expressed in deformations of the Earth s crust a definite change of facies in one and the same area is observed in time When a section of a land area sinks below sea level its shore is flooded and the coastal belt moves inland As a consequence the coarsest sediments gradually move in the same direction as the sea In the end the coarse sediments will be slowly covered by ever finer material (Fig 83) This is called a transgressive series of sediments because it is evidence that a section of the sea is growing deeper and consequently that the sea is encroaching upon the land

The reverse is observed when the sea retreats Coarse material will move in the same direction as the sea and cover ever finer sediments In this case the bottom layers will consist of the finest and the top layers of the coarsest material This series of sediments is called regressive

Fig 83 Distribution of marine facies during a transgression of the sea
1—gravel 2—sand 3—clay 4 limestone

Repeated deformations of the Earth s crust may be accompanied by repeated transgressive and regressive movements of the sea and by the superimposition of sediments of one over other facies

In the long run the destructive and constructive work of the sea changes the outlines of shores levels out the relief of the Earth s surface through the denudation of continents and the filling of sea troughs where sediments accumulate This process of rock accumulation in seas and oceans began with the beginning of time Today these rocks lie in thick series and make up the upper part of the Earth s crust

GEOLOGICAL ACTIVITY OF LAKES AND SWAMPS

Lakes Lakes are sheets of water on the surface of continents They have no direct outlet to seas The centre of a lake is usually deep and no offshore vegetation can grow there The size of a lake ranges from less than one square kilometre to such giant reservoirs as the Caspian and Aral seas whose water area extends over tens and hundreds of thousands of square kilometres

The hollows or basins holding lakes owe their origin to various factors There are numerous lakes whose basins have been carved out by ancient glaciers Some of the basins those of lakes Baikal and Issyk Kul for example,

are tectonic depressions (grabens), most of which are very deep In mountain regions lakes frequently form as a result of the damming up of rivers by rock falls for example lakes Sarez and Yashik Kul in the Pamirs Lakes also occupy the craters of extinct volcanoes or karst sinks

Lakes occupy 6 1 per cent of the Earth s land area The water regime and the mineral content of the water depend on the climate

The following figures show the salinity of some lakes (in per cent)

Caspian Sea	1 6
Aral Sea	1 08
Dead Sea	23 7
Lake Saki	27 1
Lakes Elton and Baskunchak	[illegible] 2

According to their water regimes lakes are divided into the following two groups

1 Running water lakes which are fed by rivers and give their water to other reservoirs or rivers (for example lakes Ladoga and Baikal)

2 Lakes without outlets These are fed by rivers but expend water only on evaporation (the Caspian and Aral seas—the former receives its waters from the Volga the Ural the Kura the Terek and other big rivers and the latter from the Syr Darya and the Amu Darya Lake Balkhash which is fed by the Ili Issyk Kul which is fed by the Karakolka and other small rivers)

The geological importance of running water lakes and lakes without outlets is extremely varied

Running water lakes receive mineral sediments transported by rivers and the manner in which they are filled depends on their size and depth Shallow lakes usually accumulate only coarse mineral material the silt is carried away by outflowing rivers On the other hand the water of the rivers flowing out of big lakes is in most cases absolutely transparent An example of this is the Angara River which flows out of Lake Baikal Its waters are transparent in winter and summer alike Small and shallow basins are obviously filled with detrital deposits faster than big and deep lakes Another point that must not be

overlooked is that sediments are accumulated faster near the mouths of inflowing streams and along shores

Fig 84 Beach barrier on the shore of Lake Imandra in Khibiny

In lakes as in seas and oceans, water masses move in waves but tides play hardly any role at all In some of the big lakes a movement of the water table caused by a change in the barometric pressure of the air can be observed in calm weather the water table rises a few centimetres along one shore and falls correspondingly along the opposite shore These variations in the surface level of lakes are called seiches

Waves which in some lakes reach a height of three or four metres play an important role As in seas they wear away shore protuberances the abraded material is transported and sorted (Fig 84) Wave abrasion is also important in the Rybinsk Tsimlyanskoye Kuibyshev and other man made seas in the Soviet Union It frequently destroys shore structures That explains why the abrasion of water basin shores is studied so closely

The shallow water regions of running water lakes are usually overgrown with rushes sedge and other moisture-loving vegetation As they wither the plants fall to the bottom of the basin and stimulate the development of luxuriant fungi A mixture of mineral and organic silt called *sapropel* (putrid slime) thus forms on the floor of lakes Vegetation encroaches upon an increasing area of the water space of a lake being filled with sediments and steadily becoming shallower so that gradually the lake ceases to be a water basin and its hollow is completely filled with vegetable remains—peat

The character of the vegetation in a lake changes with time and that is why the composition of peat varies from bottom to top (Fig 85) At first the vegetation consists chiefly of rushes then equiseta and sedge appear then wood vegetation and finally moss If the rivers and underground waters feeding a lake contain salts of iron and manganese deposits of iron and manganese ore sometimes of commercial importance form on the floor of the lake

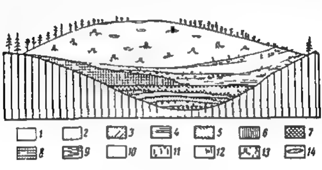

Fig 85 Structure of a bog formed as a result of the overgrowth of a lake by vegetation

1—fresh water marl 2—sapropel of peat 3—organic slime 4—reeds 5—rushes 6—equiseta 7—sedge 8—sedge willow 9—forest 10—hypnaceae 11—weld wignonette sphagnum 12—cotton grass sphagnum 13—sphagnum with pine stumps 14—moss on a sphagnum carpet

In lakes with no outlets evaporation increases the salt content of the water the highest salinity being at points farthest from the mouths of rivers Depending on the mineral composition of the water in inflowing rivers the saturated waters of a lake (brine) will precipitate halite (rock salt) mirabilite glauberite sodium carbonate or other salts These lakes are important sources of raw material for the chemical industry

Swamps Tracts of land saturated by atmospheric precipitation turn into swamps In some cases this is a seasonal phenomenon but there also are permanent swamps If atmospheric precipitation is the only source of water as for example in interfluvial areas which cannot be reached by river or ground waters there is very little mineral salts in the soil This gives rise to special swamp vegetation i e moss (sphagnum polytrichacae and so forth), which

has a very low mineral content The remains of this swamp vegetation turn into peat with a high calorie and low ash content

Peatbogs form in river valleys as well But there the swamps get their water from three sources precipitation rivers and ground waters The salt content of these swamps is much higher and the vegetation consists of rushes, sedge and shrubs The resulting peat therefore has a higher ash and smaller calorie content Iron (bog) ores occur in these low lying swamps

Over a long geological period interfluvial and low lying peatbogs develop into coal deposits As a result of diagenesis without the participation of oxygen, the carbon of the plants does not turn into carbon dioxide as when wood decomposes in the open On the contrary, it accumulates and the peat gradually is reconstructed into lignite brown or hard coal

MAN AS A GEOLOGICAL AGENT

Man's geological activity proceeds in three main directions

The first is in agriculture Man ploughs up large expanses of the Earth s surface fertilises the soil and thus considerably accelerates soil forming processes In addition man takes many measures to facilitate farming For example in some regions he drains the soil, in others he floods and irrigates it The net result of this activity is that the processes of weathering are further speeded up and developed

The second is in geology linked up with the tapping of nature s riches The development of natural resources such as ores coal and petroleum is steadily expanding and spreading to ever new areas and greater depths This wealth, given the general name of minerals occurs everywhere, but its quantity and economic importance varies Some areas for example may have huge peat deposits lying almost at the surface others have deposits of coal which, in contrast to peat frequently lie at great depths

To develop coal deposits man builds deep mines penetrates many hundreds of metres into the bosom of the Earth and brings coal to the surface through a whole system

of shafts Big hollows form in the ground where coal is extracted with the result that air with its gas moisture and so on penetrates through shafts galleries and other passages and weathering begins where normally it would not have occurred By bringing great quantities of minerals and "barren" rock to the surface of the Earth and forming large waste piles at the mouths of pits man changes the appearance of the Earth s surface and also the conditions

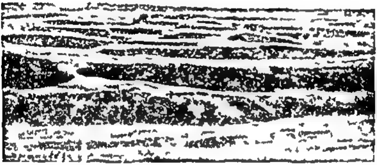

Fig 86 Sinking of the surface of an abandoned coal field

in its interior This activity results in the deformation and sinking of the surface layers overlying man made hollows (Fig 86)

To develop oil and gasfields man has to drill wells some of which are five or six kilometres deep By so doing he evidently starts a series of new processes which otherwise would have proceeded very slowly or would not have taken place at all Surface layers may also be deformed by the extraction of large quantities of oil

The Earth s surface is changed radically through the development of iron copper tin lead and other metal deposits To extract these minerals man builds deep mines Thus exploiting mineral resources man bodily interferes in the life of the Earth s crust

Lastly the third direction of man s geological activity

consists in building surface and underground structures In order to erect tall buildings big mills and factories and other structures man builds deep foundations for them He penetrates still deeper into the Earth when he builds tunnels for subways in cities and also for railways through mountains

Man s importance as an agent accelerating the dispersion of mineral masses that had accumulated over a period of many hundreds of thousands of years will be readily appreciated if the duration and scale of his geological activity is taken into consideration

This activity is growing in intensity with the growth of man's knowledge of nature and with the development of machines

DIAGENESIS

The formation of sediments may be described as an accumulation of the products of mechanical chemical and organic decay on the floor of basins or on land Sediments never remain constant When we compare sedimentary rocks of marine or continental origin with the aqueous or terrestrial deposits that accumulate before our eyes, we shall notice many distinguishing features that are due to the changes that take place after sediments are laid These changes are caused by the physical, chemical and biochemical processes in sediments due to interaction with the environment These changes embracing dissolution recrystallisation, formation of concretions coal and so forth are collectively called *diagenesis*

In diagenesis a very essential role is played by chemical reactions and the activity of organisms (bacteria) Through these processes sediments undergo substantial changes and gradually turn into rock

Dissolution This process may embrace only the top or the entire series of sediments on the floor of a basin Organisms with easily soluble skeletons (consisting of calcium carbonate) are dissolved partially as they sink to the sea floor after death During life their skeletons are protected against dissolution by an organic jacket, which is destroyed when they die

It has been noticed that many fresh water mollusks the common pond edentata for example, whose shell is protected by a chitin sheath are likewise dissolved after death

Shells consisting of conchite substances dissolve faster than any others shells consisting of calcite have a greater resistance to the dissolving action of water Remains of marine vertebrates able to resist dissolution best of all for example the auditory mechanism of fishes and shark s teeth are brought to the surface from the ocean floor during deep sea investigations All other parts of the skeletons disappear without a trace, dissolving in sea water The silicic skeletons of organisms forming siliceous sediments take much longer to dissolve

Recrystallisation One of the processes of diagenesis is that of the recrystallisation of dissolved elements On the floor of basins sediments contain particles of mineral and organic matter As diagenesis proceeds the organic elements in a sediment disintegrate into various new compounds These compounds interact with the mineral elements in the sediment to produce new minerals while some of the existing minerals recrystallise In this way lime ooze for example turns into limestone

A silica rich rock called gaize forms when sponge spicules diatom shells and so on are dissolved in the sediments on the sea floor The dissolved material is precipitated as opal or chalcedony and cements the clastic elements of a sediment or fills the inner cavities of organisms

Recrystallisation is sometimes a very rapid process as, for example during the diagenesis of coral reefs whose organic base becomes filled with crystalline limestone Similar regenerations into solid limestone in which traces of organic structure cannot always be found are observed among reef building calcareous algae The rapid regeneration of organic deposits into crystalline limestone is due mainly to the carbon dioxide liberated during the decomposition of the organic matter of algae Carbon dioxide intensively dissolves lime which after the carbon dioxide evaporates is precipitated in crystalline form

Formation of Concretions A variety of septarian nodules or growths (concretions) are frequently separated when rocks dissolve and recrystallise The shape of these con

cretions ranges from spherical and ellipsoidal to botryoidal and dendritic Frequently nodules are concentric with the mineral shells overlapping each other They usually form round some crystallisation centre such as a mineral or shell fragment

Examples of concretions are calcerous nodules in argillaceous or marly deposits Concretions of ferrous carbonate, barium carbonate silica and phosphate of lime (phosphorites) occur frequently The latter are a very valuable raw material for the chemical industry particularly for the production of fertiliser (superphosphate)

Concretions usually have hollows which are filled by calcite quartz, pyrite or some other mineral crystals and are called *geodes*

Dolomitisation The formation of dolomites is another manifestation of diagenesis It is surmised that when the magnesium chloride of sea water interacts with calcium carbonate it turns into magnesium carbonate while the calcium carbonate which dissolves rapidly is carried away by water currents In one way or another organic processes also contribute to the dolomitisation of limestone

It has been found that up to 43 per cent of some fossil shells which contained only traces of magnesium during the lifetime of the animal consist of dolomite This shows that in fossil limestone the dolomitisation cycle takes a very long time

Decomposition of Silicates Silicates decompose under the action of sea water It has been established that at depths of over 4 000 metres the ocean floor is covered with red clay composed of the products of the decomposition of silicates which reach the floor as volcanic or cosmic dust

Red clay is composed chiefly of iron rich hydrous silicates and also of substantial admixtures of other minerals and remains of silicic organisms There is very little, not more than one per cent lime in this clay The various nodules that occur in it are mostly manganese oxides which are regarded as the products of the decomposition of volcanic dust Iron is also found in manganese concretions

Role of Bacteria Organic substances decompose rapidly on the sea floor particularly where bacteria participates in the process The molecules of organic substances consist

of carbon oxygen hydrogen nitrogen sulphur phosphorus iron and some other elements Binary compounds, in which water carbon dioxide hydrocarbon, ammonia hydrogen sulphide hydrogen phosphate and other elements play a part form when organic matter decomposes under the action of bacteria These compounds dissolve easily in water and influence the minerals with which they come into contact It is believed that phosphorites are a product of this decomposition

Sulphates and Sulphides Sulphates (sulphate compounds) form in the sea The action of sea water transforms sulphate salts For example under the action of carbon they turn into carbon dioxide and sulphides which are sulphurous compounds of sodium potassium calcium and magnesium Under the action of carbon dioxide sulphides turn into carbonate compounds and precipitate hydrogen sulphide

Sulphur and Hydrogen Sulphide Alkaline compounds are dissolved and carried away by sea water while calcium carbonate is precipitated in the form of a powder like sediment Bacteria play an important role in this process They also quicken the decomposition of organic substances and in some cases cause pure sulphur to be precipitated Sulphur may thus separate from albumens and then turn into hydrogen sulphide In lakes lagoons and seas the water contains a large quantity of calcium sulphate and through the bacterial process it may become enriched with hydrogen sulphide

In this respect the Black Sea may serve as an example It is a deep depression separated from the Mediterranean by a high sill (the Bosporus is nowhere deeper than several tens of metres) In the Bosporus there is a double current fresher water flows into the Mediterranean from the Black Sea on the surface while heavier salt water flows on the bottom in the reverse direction from the Mediterranean to the Black Sea This water cycle only embraces a thin layer of water not exceeding 200 metres there is enough oxygen in this layer to allow organic life to flourish Deeper there is hydrogen sulphide whose quantity increases with depth This hydrogen sulphide forms through the vital activity of bacteria developing on the floor That is why

no organisms except sulphobacteria can live in the deepest parts of the Black Sea

Lake and Bog Ores Iron accumulates and the reduction of ferric oxide [Fe_2O_3] into ferrous oxide [FeO] is observed in fresh water basins Here the leading role is played by special bacteria that consume oxygen and release carbon dioxide This process is very widespread in nature and leads to the accumulation of iron ores known as lake bog meadow and other ores

Hydrocarbons The decomposition of organic substances may result in the formation of hydrocarbons of which the most important are 1) methane or combustible gas which is often liberated from the Earth in natural conditions 2) petroleum and other liquid hydrocarbons 3) ozocerite or mineral (fossil) wax, which is a mixture of solid hydrocarbons and 4) asphalt which is a product of petroleum oxidation

Sapropel Organic ooze or sapropel in which a large quantity of fresh-water algae is buried accumulates on the floor of many fresh water lakes In some cases this ooze is a mixture of organic and inorganic substances in which the former are represented by the remains of microscopic plants and organisms animal debris and so forth In the course of diagenesis such ooze may yield many organic compounds Various organic products including benzine petroleum and paraffin have been obtained from sapropel in the laboratory

Diagenesis is observed in continental deposits as well

Peat Coal Anthracite Another manifestation of diagenesis is the transformation of plant remains into peat and, further into brown coal hard coal and anthracite If plants decay in the air, their organic parts disintegrate completely and only a small quantity of mineral (ash) substances remain On the other hand if they decay where no oxygen reaches them part of the carbon combines with oxygen and is liberated as marsh gas but the greater portion of it remains The hydrous elements are removed from plants and the vegetable mass is enriched with carbon, i e it coalifies

Carbon accumulation may be divided into the following stages formation of peat, brown coal hard coal and lastly

anthracite In wood the carbon content averages about 48-49 per cent in peat up to 52 per cent, in brown coal up to 62 per cent in hard coal up to 84 per cent and in anthracite up to 92 per cent

Compared with peat brown coal is a more compact brown black mass with an uneven earthy fracture Usually vegetable remains can be noticed in it The transitory product between peat and brown coal is called lignite and retains the form and structure of wood

Hard coal is tough black and very dense There are many varieties of this coal Some are lustreous fatty in appearance burn with a smoky flame and turn into coke when burned without oxygen others have a dull lustre and burn with a colourless flame Some coals release a large quantity of hydrocarbon and are used for the production of coal gas others on the contrary have a very low gas content

Anthracite is very hard and has a black metallic lustre with a greyish tint Although it does not catch alight easily it has a very high calorific capacity

Hard coal that forms in areas that had once been covered with vegetation is called autochthonous If the vegetable material for its formation is brought from afar it is called allochthonous coal

Autochthonous coal accumulates in vast swamp ridden areas Allochthonous coal may in time form in the mouths of the Yenisei the Lena and the Ob which carry huge masses of vegetable material that is subsequently buried in the sediments of the Arctic Ocean

ENDOGENOUS PROCESSES

In the development of the Earth's crust an important role is played by geological processes engendered by the internal forces of the Earth. These are called endogenous processes and they include the intrusion of magma into the Earth's crust and its ejection to the surface from the interior of the Earth, tectonic movements of the Earth's crust leading to periodic slow uplifts and subsidences of separate regions, sharp and sometimes very violent tremors in some parts of the Earth, disturbances in the horizontal bedding of rock series.

Hypotheses are all we have to go by as regards the nature of the internal forces causing the above processes. The chief of these hypotheses are discussed below.

IGNEOUS ACTIVITY

The Earth is a solid body with a definite thermodynamic equilibrium at various depths. This equilibrium was established in the process of the Earth's development. A disturbance of this equilibrium in any area (i.e. a drop in pressure or a rise in temperature) rapidly transforms the Earth's mass in the affected foci from a solid to a liquid state. This transformation is accompanied by a colossal increase in volume and by the flow of the resultant white-hot silicate mass (magma) to the weakened crustal areas where it sometimes rises to the surface.

Magma forms at great depths (over 60 kilometres), where the temperature (1,200-1,500° C and over) exceeds the melt-

ing point of rock It is forced to the surface evidently by hydrostatic pressure while because the pressure drops the gases in the magma are frequently released through a series of explosions leading to a rapid manifestation of igneous activity

The term igneous activity covers the range of processes linked up with the activity of the Earth's internal forces and manifested in the intrusion of magma into the Earth's crust or its eruption to the surface with subsequent solidification In the first case we deal with intrusive and in the second with effusive igneous activity or volcanism

The solidification of magma produces magmatic rocks which depending on how they were formed are classified as intrusive (abyssal) effusive and hypabyssal All these rocks products of uniform primary magma differ from each other by their chemical and mineralogical composition

Magma is differentiated i e split up into layers of different composition or specific weight through various physical and chemical processes the lighter elements accumulate in the upper layers and the heavier elements in the lower layers

It is believed that magma differentiation is influenced by diffusion the passage of electric currents and other processes

The extreme forms of differentiated magma are granitic magma more than 65 per cent of which consists of silica and basaltic magma in which the silica content is less than 55 per cent Silica rich magma is called persilic and magma with a low silica content is called basic

When magma solidifies it is accompanied by the crystallisation of minerals basic minerals being the first to crystallise

When magma bursts through the rock mass of the Earth's crust it melts and absorbs (assimilates) the rocks in its path and its composition changes in the process For example after absorbing masses of enclosing rocks say limestone persilic magma loses some of its acidity In other cases after melting and absorbing quartz sandstone or any other similar rock basic magma becomes more acidic through an increase in its silica content Minerals that do not occur either in the magma or in the surrounding rocks

form at the points of contact between the invading molten magma and the cold rocks of the lithosphere These are called contact or frequently, ore minerals

Intrusive Igneous Activity

Where there is intrusive igneous activity, the magma invading the Earth s crust forms magmatic bodies or intrusions in it The size of these intrusions and their rela

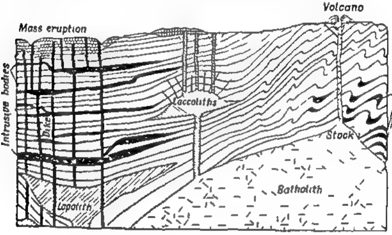

Fig 87 Stratification of intrusive and effusive rocks

tions with the enclosing rocks vary The following types of intrusions are distinguished (Fig 87)

Batholiths—*large magmatic bodies of irregular shape* with steeply dipping sides They are formed when magma solidifies at considerable depths in the central parts of folded areas The surrounding rocks are breached as it were, and for that reason batholiths are not bedded in conformity with them They are formed chiefly by *acid* rocks of the granite type (western part of the Zeravshan Range in the Pamirs)

Stocks—magmatic bodies that are considerably smaller than batholiths (less than 100 square kilometres) but with

the same conditions of formation, shape and rock components.

Laccoliths—dome-like bodies with a convex surface and a flat base. Their diameter varies from hundreds of metres to several kilometres. They dome up overlying rocks and are concordant with them. Isolated mountains in the vicinity of Pyatigorsk (Mashuk, Beshtau, Zheleznaya and others) are laccoliths. The sediments that had formerly lain on them have now been almost entirely eroded so that there are bare igneous rocks on the summits of these mountains.

Fissured intrusions form when magma enters rock fissures moving away from large intrusive bodies. Fissures may pass along the bedding of enclosing rocks (intrusive sheets) or cross it in various directions (discordant or transgressive intrusions). Correspondingly the correlation between the fissured intrusions and the enclosing rock may also be different. Fractured intrusive bodies are called *veins*. As a result of denudation the discordant rocks enclosing a vein may disintegrate, while the rocks forming the fissured intrusions remain intact and form a wall-like outlet. These formations are called *dykes*.

Sheet veins are large intrusive bodies that can be traced over big areas and occur between layers of enclosing rocks conformably with the latter. These veins can be 45-50 metres and over thick and 150-200 kilometres long; cross veins are from one to three metres thick, sometimes thicker.

A study of the bedding of intrusive bodies and the laws governing their distribution in space is important to theory and practice because deposits of many valuable minerals are related to them.

Effusive Igneous Activity or Volcanism

Volcanic eruptions are among the most awe-inspiring and formidable phenomena in nature.

When we speak of volcanoes we generally say they are active or extinct, but this division is purely conventional. There have been cases of volcanoes unexpectedly becoming active after a dormant period of many centuries; in the course

of which their sides were covered with forests and their craters became converted into lakes In practice only those volcanoes may be regarded as extinct about whose activity no information has been handed down to us Active volcanoes are considered those which continue to erupt or had erupted in the course of known history In the world today there are 476 active and more than 4 000 extinct volcanoes

Fig 88 Eruption of Mount Vesuvius

Mount Vesuvius (Fig 88) which stands on the east side of the Bay of Naples was for a long time regarded as extinct There were vineyards and orchards on its slopes In the year 79 A D the volcano suddenly showed signs of intensive activity, ejecting enormous masses of lava and ash Several thousand people perished and the cities of Pompeii and Herculaneum situated at its foot were destroyed and buried in ash The volcano has been active ever since with fairly long periods (of more than a century) of repose between eruptions There has been a marked livening up of its activity in the past 100 150 years It last erupted violently in 1944

Another example is Mount Pelee on North Martinique Island, which had likewise been for a long time regarded as extinct It erupted in 1902 destroying the city of St Pierre and killing its entire population of 29 000 with a hurricane of hot gases

Volcanoes continue to appear to this day For example Mount Paricutin which was active for almost five years appeared in Mexico on February 20 1943

Volcanoes rise on land and on the floor of oceans As a rule enormous masses of material are ejected forming huge submarine or surface structures

For example the submarine and surface portion of the Hawaiian type of volcano is about 5 000 metres An idea of how fast volcanic products accumulate is given by the eruption of the Fayal submarine volcano in the Azores North Atlantic where in 1957 a new volcanic islet appeared near the Island of Fayal in three days It grew virtually before the eyes of the seamen who watched the eruption its area increasing by 300 square metres every 12 hours

External Appearance of Volcanoes Usually volcanoes are more or less tall (up to several kilometres) conical mountains On the summit there is a hollow—a bowl or crater—through which the volcano erupts (Fig 89) A canal called a vent funnel through which the erupted material is ejected runs down into the volcano from the floor of the crater One of the world s largest volcanoes Mount Klyuchevskaya in Kamchatka (4 850 metres) is a cone Mounts Vesuvius Fujiyama in Japan Mount Kibo in Africa and others are likewise cones

The craters of many ancient volcanoes have one or several active volcanoes These craters called calderas have a diameter of several tens of kilometres

Eruption The force of individual eruptions is not always the same and alternations of periods of high and low activity may be observed in each volcano The activity of a volcano sometimes gradually increases and then slowly fades while in other cases a violent and sudden outburst takes place As we have already pointed out whole centuries sometimes pass between separate outbursts of volcanic activity

After a violent eruption some volcanoes come almost completely to rest and barely smoke at short intervals others smoke uninterruptedly and from time to time throw out stones and ash and still others periodically eject a quiet flow of lava and in the intervals between discharges their craters are filled with molten continuously moving lava

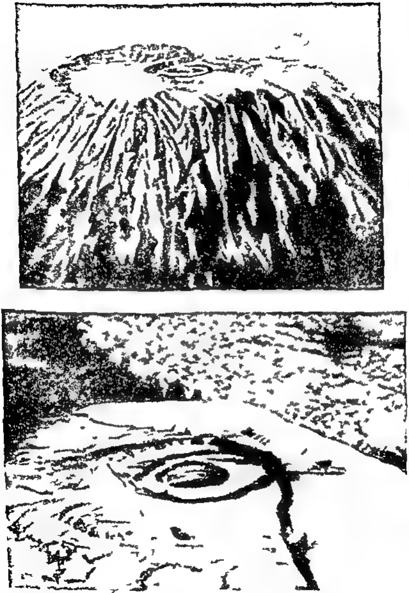

Fig 89 : Two views of the crater of Peak Kibo, Africa

Products of Eruption There are solid liquid and gaseous products of eruption The solid products include volcanic ash sand lapilli and bombs These products are, as a rule ejected in the initial period of eruption *Volcanic ash* consists of tiny particles of a mineral mass formed through the crushing of the rocks of which the vent funnel walls consist and also through the dispersal of lava The size of these particles ranges from a fraction of a millimetre to several millimetres Particles that are of the size of sand grains are called *volcanic sand* Bigger particles from one to several centimetres are called *lapilli* (small stones) The following facts show how much ash can be thrown out by a volcano When Mount Katmai in Alaska erupted in 1912 a layer of ash more than four metres thick covered the immediate vicinity while on the leeward side this layer was ten centimetres thick over a distance of nearly 100 kilometres About 20 cubic kilometres of solid material was ejected by the explosion For 60 hours the entire locality was enveloped in darkness Rain from volcanic clouds poured continuously for 25 hours

Sometimes the ash is so fine that a gas explosion lifts it to an altitude of more than ten kilometres where it is picked up by air currents and carried for a long time in the lower layers of the stratosphere In 1883 for example there was a tremendous eruption of Mount Krakatau in the centre of the Sunda Strait This eruption threw out such a colossal quantity of ash that it floated in the stratosphere for more than a year causing strange sunrise and sunset conditions

If rain falls while ash is being ejected liquid mud will rush down the slopes of the volcano causing enormous destruction in the surrounding countryside

Even big pieces of solid lava may be ejected by a volcano during violent emissions of gas Thrown into the air to a height of many hundreds of metres these pieces are given a spindle like shape by their own rotation They retain this shape if they have had time to chill before falling on the ground if not the impact flattens them out Whole sections weighing many tens of tons are sometimes torn off the rocks around the crater of a volcano Tossed hundreds of metres into the air they drop on the slopes of the volcano

These pieces of lava and rock from eight to ten centimetres to several metres in size are called *volcanic bombs* (Fig 90)

Gases ash lapilli and bombs are frequently ejected uniformly but in some cases these ejections take the form of giant explosions that blow up the crater throwing the whole cone of the volcano into the air and leaving a deep hollow in its place

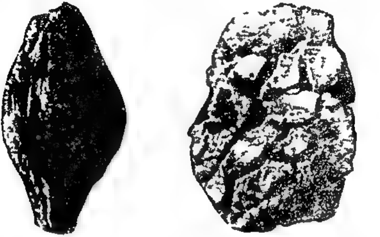

Fig 90 Volcanic bombs

The ash and sand raining down on the slopes at first are a loose mass, which gradually becomes compact under its own weight and the action of water until it solidifies into rock called volcanic tuff The volcanic ash and sand falling on the surface of lakes and seas sink to the bottom, where they are buried by silt and sand The resultant rock of volcanic and sedimentary origin is called *tuffite*

Volcanic Gases The most important of these are water vapours which often constitute a substantial part of the gaseous emissions The other gases include hydrogen chlorine sulphur nitrogen carbon oxygen sometimes carbon dioxide and methane and in many cases hydrogen chloride hydrogen sulphide sulphur dioxide ammonia ammonium chloride and ammonium carbonate

Gases issue not only from the crater itself but also from rents on the slopes of the volcano and at its foot These smoking rents are called *fumaroles* The gases are liberated as dense vapours or smoke The chemical composition of fumaroles depends largely on the temperature which is very high at the beginning of an eruption especially around the crater and then falls at the end and after the eruption At the beginning of an eruption fumaroles consist chiefly of halogens (Cl F) and when the temperature drops to 100 180 C sulphur dioxide begins to predominate in them Fumaroles in which sulphur dioxide predominates are called solfatara The next stage (in some volcanoes) is one in which boron (soffioni) predominates and in the last stage of its activity (moffette stage) a volcano liberates carbon dioxide

Volcanic Lava Lava is the molten mass ejected by vol canoes The difference between lava and magma is that it degasses as it issues from a crater Its temperature is usually 1 000 1 200°C

The chemical composition and physical properties of lava vary In some cases there are large quantities of silicon oxide (acid lava) This lava is very viscous and forms blocks of molten material Lava containing a smaller quant ity of silica is more fluid (basic lava) The most mobile are ultra basic lavas

The lava that was ejected by Mount Pelee is an example of acid viscous lava It was so dense that it formed a kind of tower over the crater This tower was nearly 300 metres high but it cracked and disintegrated as it cooled

The lava of the volcanoes on the Hawaiian Islands is quite different in composition and its properties are different too It is of the basaltic type which is rich in ferruginous and magnesial compounds and poor in silica It is so fluid and mobile that it forms streams flowing down the slopes of volcanoes and where there are benches it rushes down like a waterfall to form a lava cascade (Fig 91)

Acid lavas which are lightly (pink grey) coloured are relatively light viscous rich in gases and cool slowly Basic lavas are dark (dark grey green black) fluid and fusible and have a low gas content

All products ejected by volcanoes take part in forming the Earth s crust They account for 51 52 per cent of the

rocks ejected to the surface The diversity of the ejected rocks is due not to any diversity of the initial magma material, as was formerly thought, but to differences in the common magma s specific weight temperature the crystallisation of the various components in it and so on

Most authors agree that common magma has a basaltic type of composition

Fig 91 A lava cascade in Hawaii

At a given eruption the mineral composition of lava is the same as that of its solid products (volcanic ash lapilli and bombs)

The quantity of products ejected by a volcano differs with every eruption Volcanologists consider that since the year 1500 to our day the Earth s volcanoes have ejected not less than 300 cubic kilometres of loose products and 50 cubic kilometres of lava

The structure of a volcanic cone depends on the nature of the products ejected by the volcano A volcano that ejects principally lava will have very gentle slopes even if it is a very tall mountain

A volcano that builds its cone of cooled streams of lava and layers of tuff has steep sides (the angle sometimes being as high as 35-40°)

A feature of some volcanoes is that they erupt not only through their craters but also through fissures in the slopes

and at the foot These small craters are called parasitic volcanoes and are to be seen on Mount Etna and other volcanoes

Classification of Volcanoes By the character of their activity volcanoes are classified as follows

1 *Hawaiian Type* This type occurs on the Hawaiian Islands (Mauna Loa Kilauea and others) They are characterised by mobile lava of basic (basaltic) composition and a quiet emission of gases and vapours hardly any solid products are ejected The lava filling the craters is in continuous motion and boils slowly all the time It sometimes spurts out in fountains that rise for a few minutes to a height of several tens of metres and then disappear After the crater is filled to the brim lava flows down the sides of the volcano The size of the lava streams which are sometimes huge and stretch for scores of kilometres depends on how much lava issues into the crater from the depths of the Earth These volcanoes have gently sloping sides

2 *Strombolian Type* This type is represented by the volcano Stromboli in the Mediterranean It likewise ejects basaltic fluid lava but in contrast to the Hawaiian volcanoes it liberates large quantities of gases and casts up bombs and ash The bombs are frequently twisted and the lava as in the case of the Hawaiian volcanoes has a wavy surface

3 *Vesuvian Type* The lava from these volcanoes contains a somewhat greater quantity of silica it is more viscous and frequently corks up the crater vent with the result that gases and vapours accumulate deep in the ground This is often the cause of underground tremors before an eruption and then of a powerful explosion that throws a great mass of ash lapilli and bombs into the air Because the lava is viscous the bombs are not twisted and when they fall on the ground they flatten out into pancakes The streams of lava do not spread far and when they cool they form shapeless boulders This type includes the volcanoes in Kamchatka Mount Etna in Sicily Vesuvius in Italy and Mount Vulcano on the southernmost of the Lipari Islands in the Mediterranean

4 *Pelean Type* This type of volcano ejects viscous lava which hardens in the volcano vent blocking the

passage for gases and vapours That explains why eruptions are accompanied by violent underground tremors and by explosions that cast up an enormous quantity of vapours gases ash, lapilli and bombs These volcanoes release very hot gases (700°C and over) For that reason the clouds of gas and ash coming down the slopes with the velocity of an atmospheric cyclone (scorching clouds) destroy everything in their path Such clouds destroyed the town of

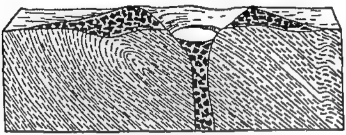

Fig 92 Section of a maar

Saint Pierre on Martinique Island when Mount Pelee erupted

5 *Bandai Type* Eruptions of these volcanoes are accompanied by severe tremors and explosions and the casting up of huge quantities of gases and ash A violent explosion sometimes blows off an entire volcano as was the case with Bandai Krakatau Katmai and other volcanoes There may be no lava during an eruption, the reason being evidently that the magma feeding the volcano has a very high acid content and is consequently extremely viscous

6 *Volcanic Pipes* (*Diatremes*) These volcanoes form as a result of a single violent emission of gases without the appearance of lava They consist of an oval vent, whose mouth or crater is a cup shaped hollow with gently sloping sides and with a diameter ranging from several tens of metres to three or four kilometres The floor of the crater is below the Earth s surface The craters of some of these volcanoes are surrounded by a rampart of ejected volcanic tuff fragments Some craters are occupied by lakes (maars) (Fig 92) but in most cases they have been completely

destroyed by exogenic processes and the vents (explosion pipes) reach the surface Volcanoes of this type occur in Germany (there are nearly 130 in Eifel), Africa (the diamond bearing pipes in the Kimberley Mountains) the Soviet Union (Kimberley type pipes in Yakutia) Mexico and other areas

Fissure Volcanoes The volcanoes described above have a definite feeding centre and are therefore called central volcanoes In contrast to them there are fissure volcanoes which eject gases and lava not through a central crater but through tectonic fissures In some places fissures may appear as volcanic piles fed from a common magmatic chamber The volcanoes in Iceland are typical examples Some of the fissures are 40 kilometres long and eject huge masses of lava which covers large areas on either side Frequently along fissures there are rows of volcanic piles

Many fissure volcanoes are not conical and the lava spreads on the surface These lava sheets differ from the lava streams of central volcanoes The latter are rarely wider than a kilometre at the base of the volcano or thicker than 100 metres they are 15-20 kilometres long and sometimes longer In contrast the lava sheets frequently occupy enormous areas The sheets of some ancient volcanoes cover areas of tens and hundreds of thousands of square kilometres (in Armenia the Deccan Plateau in India in South America and elsewhere)

At present chiefly central volcanoes occur Fissure and areal eruptions predominated in distant geological epochs when the Earth s crust was thinner

Lava pouring out to the surface forms streams sheets and domes It hardens into a crust which is a poor conductor of heat with the result that lava continues to flow under this crust for many days after an eruption That is why there are so many hollows in lava streams and sheets Some of them are very big On the slopes of Mount Shasta California for example there is a hollow which is 20 25 metres high 6-20 metres wide and more than 1 5 kilometres long The thickness of the roof varies from 3 to 20 metres

In the U S S R there are hollows in lava sheets around Lake Sevan in Armenia Dry hollows are often used as enclosures for livestock

Fissures and faults which break the rock complex into more or less regular jointings, form on the surface of lava as a result of asynchronous hardening. Columnar and prismatic jointings are a feature of basic rocks, and hummock and other jointings—of acid rocks.

Distribution of Volcanoes. Volcanoes are unevenly distributed on the Earth's surface. Some continents, Australia, for example, have no volcanoes at all. In Europe, if Sicily and the islands adjoining it are not taken into consideration, there is only one volcano—Vesuvius, which stands in the Apennines. Africa has quite a few. In Asia they are concentrated in Kamchatka. A group of apparently extinct volcanoes is known in Manchuria. In the Caucasus Mounts Elbrus and Ararat were active at a comparatively recent date. Two big volcanoes have been discovered in the Antarctic. The largest number of known volcanoes is on the Pacific seaboard of America.

The principal volcanic region is in the Pacific islands adjoining the Asian continent: the Aleutian Islands, the Kuril Islands, Japan, the Sunda Islands, the Philippines, New Guinea, and others. Some of the volcanoes on these islands are huge structures characterised by intensive activity. In the Atlantic Ocean there are volcanoes in Iceland, on the Cape Verde Islands, the Canary Islands, and the Lesser Antilles.

The main regions where volcanoes occur are thus the Pacific volcanic ring, the Mediterranean latitudinal belt, the eastern margin of the Atlantic and the East African meridional belt.

Geological data shows that all volcanoes are related to areas of comparatively recent tectonic faults in the Earth's crust. These faults usually lie along the coast of oceans and seas, but many occur deep inland as well.

Volcanoes in the U.S.S.R. The Soviet Union has active volcanoes in Kamchatka and on the Kuril Islands. These belong to the Pacific ring.

The volcanoes in Kamchatka were first described by S. Krasheninnikov, who gave a general idea of the volcanic nature of this peninsula. Early in the twentieth century, the Kamchatka volcanoes were investigated by K. Bogda-

novich S Konradi and V Komarov and in recent years by A Zavaritsky

The Kamchatka volcanoes are arranged in three more or less parallel rows stretching along the peninsula parallel with its three mountain ranges Altogether there are 180 known volcanoes in the peninsula Of these 22 are active and 158 have shown no signs of activity as long as man can remember All are in the southern half of Kamchatka the active ones being concentrated in the eastern part the northern part of the peninsula is evidently, devoid of volcanoes

Mount Klyuchevskaya (4 850 metres) is the biggest of the Kamchatka volcanoes It is the third highest volcanic cone in the world after Mount Kilimanjaro (6 110 metres) in Africa and Mount Cotopaxi (5 960 metres) in the South American Andes Klyuchevskaya erupts very frequently Sometimes these are short explosions, but there have been periods when the volcano was continuously active for three years consecutively Klyuchevskaya s last major eruption took place in 1956 (Fig 93)

Next to Klyuchevskaya there are the large Mount Utkinskaya (3 352 metres) and the somewhat smaller Mount Krestovaya These three form a single volcanic group

South of this group is the active flat Mount Tolbachik and on the shore of Kronovaya Bay stand Mount Kronotskaya (3 033 metres) Great and Little Semyachiki Mount Zhupanova (2 580 metres) Mount Avachinskaya (2 547 metres) and Mount Koryatskaya (or Streloshnaya) On the southernmost tip of Kamchatka are mounts Viluchinskaya Opalnaya Galigina and Yavina

Near Klyuchevskaya there is a volcanological station that keeps it and other Kamchatka volcanoes under observation More information is available about Klyuchevskaya than any other Kamchatka volcano It has been learned that there have been about 20 major eruptions in the past 200 years The volcano is active all the time releasing a small quantity of gas and ash during periods of relative calm From time to time it also ejects some liquid lava which is adding to the height of the cone On its peak the volcano wears a cap of eternal ice

During periods of intensive activity Klyuchevskaya sometimes disgorges as much as four and a half cubic kilometres of lava Compared with the volume of the volcano itself (3 400 cubic kilometres), this quantity shows that about 700 *major eruptions were required to form* Klyuchevskaya s present cone Available data indicate that the volcano

Fig 93 Eruption of Mount Klyuchevskaya

ejects large quantities of lava once every seven or eight years On the basis of this data it may be surmised that Klyuchevskaya appeared about 5 000 years ago (providing the character of its activity has remained unchanged in this span of time)

Mud Volcanoes Mud volcanoes or mud cones are pseudo *volcanoes of exogenous origin Outwardly they* are small copies of volcanoes and are widespread in oilfields There are mud volcanoes for example in the Taman and Kerch peninsulas in Kabristan (Azerbaijan) and also in Rumania China Italy and other countries

They occur over faults in the upper layers of the Earth's crust and are conical elevations with a crater on the summit. Mud and petroleum gas, often self igniting, are ejected periodically through the vent. The size varies from a few centimetres to hundreds of metres. The cones of mud volcanoes consist of rock fragments cemented together by ejected clay.

This clay is mixed with water containing salts of sodium chlorate, sodium sulphate, boron, iodine and bromine. Fairly hot, it flows peacefully out of the crater, but from time to time the volcano ejects a large quantity of highly inflammable hydrocarbon gas. A column of flame sometimes shoots scores of metres into the air.

Salses resemble mud volcanoes in size and appearance. They occur around active and recently extinct volcanoes, i.e., they are associated with post volcanic activity. During an eruption they eject water vapours, mud (a mixture of clay and ash), hydrogen sulphide and sulphur oxide. There are salses in Sicily, Java and other areas.

Geysers and thermal and thermo mineral springs are also associated with post volcanic activity.

MOVEMENT OF THE EARTH'S CRUST

The Earth's crust is in constant motion through the action of internal forces. This is manifested in huge downwarps and uplifts, the compression of layers into folds and the rupturing of rock strata.

These movements are due to what are called tectonic forces, whose activity introduces essential changes into the structure of the Earth's crust. The activity of the Earth's internal forces manifests itself most strikingly through earthquakes—crustal movements that can be directly observed and studied.

Earthquakes

Earthquakes are natural calamities. They devastate big areas, take a large toll of human lives and destroy whole towns. However, the yearly number of destructive earth

quakes rarely exceeds ten although the Earth s crust annually experiences several hundred thousand shocks and seems to be continuously pulsating Most of these shocks are very weak and can only be registered by instruments called seismographs The science of earthquakes is called seismology

Origin of Earthquakes Earthquakes are divided into three groups depending on the causes that produced them

1 Fall earthquakes—caused by large rock falls down the sides of mountains or the collapse of the roofs of caves They have an insignificant radius of action

2 Volcanic earthquakes—caused by the activity of volcanoes In many cases these earthquakes precede volcanic eruptions but most frequently they accompany them Volcanic earthquakes are felt over an incomparably larger area than earthquakes of the first group

3 Tectonic earthquakes—accompany mountain making processes They are the most widespread type of earthquake

Fall Earthquakes These earthquakes may be described as pseudo seismic phenomena

Volcanic Earthquakes In regions with active volcanoes Kamchatka for example violent shocks frequently precede or accompany the eruption of volcanoes Severe earthquakes accompanied the eruptions of Mauna Loa and Kilauea on the Hawaiian Islands A catastrophic earthquake accompanied the eruption of Krakatau in the Sunda Strait The explosion and shock gave rise to an enormous tidal wave which swept the entire population off the low lying islands in the region of the volcano and wrought great destruction in Sumatra Java and other neighbouring islands

Tectonic Earthquakes These earthquakes occur chiefly in the sialic shell, at depths of up to 70 kilometres Earthquakes have also been registered at greater depths—800 kilometres in the Sea of Okhotsk

Earthquakes caused by tectonic forces are concentrated in two regions one is in the belt of mountain ranges encircling the Pacific Ocean and embraces the adjoining islands and peninsulas the other stretches eastward from the Gulf of Mexico embraces the Mediterranean seaboard and links up with the Pacific earthquake belt via the Caucasian and Central Asian mountain systems Other *seismic areas*

include the Mid Atlantic Range and the region of the great lakes in East Africa Earthquakes thus occur in regions of recent orogeny (Alpine folding) and in adjoining regions of old orogeny that are undergoing modern (Alpine) folding i e are in a stage in which the geological structure is changing Earthquakes are much more violent in the latter

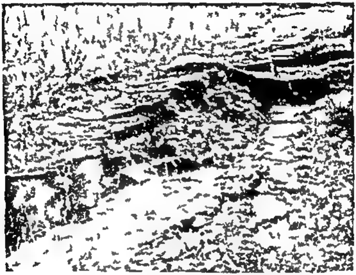

Fig 94 Cracks formed by an earthquake

regions because of the faulted structure Moving at various speeds in different directions these faults open the ancient faults that had been closed by igneous activity and cause new faults to appear This activity is accompanied by severe earthquakes such as the 11 12 point earthquake in the Gobi Altai area in 1957 For its microeffect it was the most violent earthquake in history Repercussions of the earthquakes in these regions are felt over enormous distances In 1940 for example the shocks caused by an earthquake in the Carpathians were felt in Moscow Kharkov Voronezh Kiev Lvov and other cities between Moscow and the Carpathian Mountains These flatland earthquakes

are rare phenomena and never cause any noticeable destruction or casualties

Earthquakes are much stronger in mountain and piedmont regions regarded as young folded structures Severe

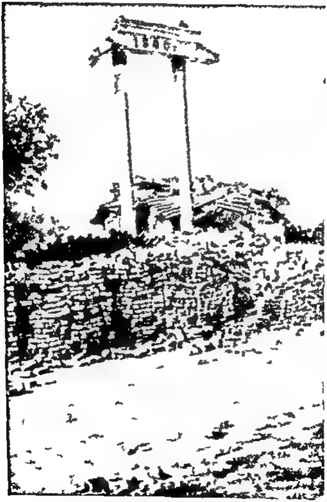

Fig 95 This house destroyed by the 1948 earthquake in Ashkhabad was built of poor material

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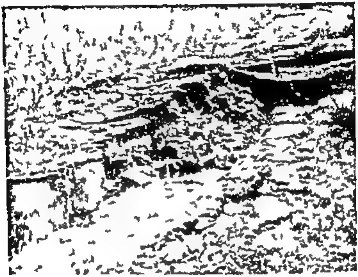

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is traced on this cylinder when there are no earthquakes and the ground does not vibrate But when there is a trem or the pendulum remains at rest thanks to the weight but the cylinder starts revolving and the point of the pen-

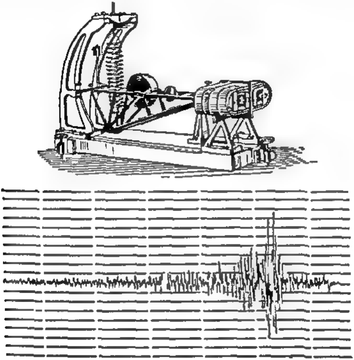


Fig 96 A Golitsyn seismograph and a seismogram produced by it

dulum traces a wavy line on it The size of the waves of this line depends on the force of the tremors The resultant record is called a seismogram A vertical pendulum is used for recording horizontal vibrations Vertical vibrations are recorded with a horizontal pendulum The true direction of vibrations is determined with both pendulums working simultaneously

The Golitsyn seismograph is an improvement over all existing instruments of its kind It is used by seismological stations in the Soviet Union and abroad (Fig 96)

earthquakes occur for example in the Tien Shan and Pamir mountains The city of Alma Ata was shaken by violent earthquakes in 1852 and 1911 The latter earthquake (January 4) occurred in the Kebin River valley somewhat to the south of Alma Ata It was exceptionally severe both as regards its force and area of propagation The under ground shocks from this earthquake were felt in an area of more than a million square kilometres The shock wave spread all over the Earth and circled the globe three times In some areas so many cracks appeared in the ground that it seemed it had been furrowed by a gigantic plough (Fig 94)

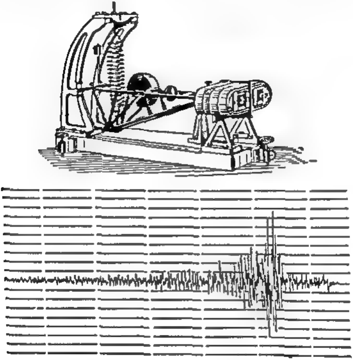
The shocks from the earthquakes in the foothills of the Pamir and Tien Shan mountains are likewise fairly severe In Tashkent and Samarkand for example they cause cracks to appear in walls and destroy badly built houses There were destructive earthquakes in Ashkhabad in 1929 and 1948 (Fig 95) whose hypocentres were at a depth of 15 20 kilometres The hypocentre of the destructive Agadir earthquake in 1960 was at a depth of five to ten kilometres

Severe earthquakes occur almost throughout the area covered by the two above mentioned belts (in Italy, China Japan and other countries)

Epicentre and Hypocentre The force of earthquakes is not the same at different points of the Earth s surface The point on the surface where an earthquake achieves its greatest force is called the epicentre Vertically beneath it is the hypocentre the point where an earthquake origi nates Under the influence of for example tectonic forces powerful shocks occur in the hypocentre These cause un dulatory o cillations that are transmitted vertically to the epicentre and also horizontally along spheroidal sur faces throughout the entire body of the Earth

Seismograph and Seismogram The tremors started by these shocks are studied on the Earth s surface with in struments called seismographs which are a kind of pen dulum There are a great variety of pendulum systems If the pendulum is vertical a weight with a tapering point is suspended from it on a thin wire The point is set over a cylinder which is turned by clockwork A straight line

is traced on this cylinder when there are no earthquakes and the ground does not vibrate But when there is a tremor the pendulum remains at rest thanks to the weight but the cylinder starts revolving and the point of the pen



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The design and operation of seismographs have been further improved in the Soviet Union in recent years. The new instruments developed by P. Nikiforov, V. Bonchkovsky, D. Kirnos and D. Kharin proved to be the most sensitive and are in use at new seismological centres in the Soviet Union.

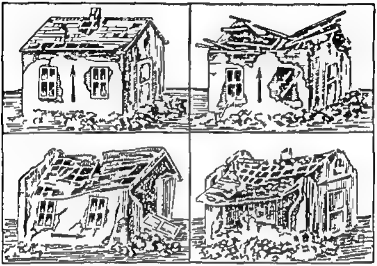

Fig. 97. A house destroyed by shock waves moving in different directions

Movement of the Earth's Crust During Earthquakes

By comparing seismograms it was found possible to establish the nature of the movements arising in a hypocentre. Two types of vibrations have been distinguished: 1) *longitudinal* or compressional, and 2) *transversal* or distortional.

Longitudinal vibrations give rise to very fast moving seismic waves that travel at a rate of seven or eight kilometres per second in resilient rock and at a somewhat lower rate in loose rocks. The velocity of transversal waves is about half that of longitudinal waves. The latter, therefore, reach the epicentre first and are the first to be registered by a seismograph.

Surface or long waves that fan out in all directions arise in the epicentre Though these waves move at about half the speed of transversal waves they are much more destructive The degree and nature of the destruction caused on the surface of the Earth and to structures depend on the direction of the shock wave (Fig 97)

Surface waves resemble the waves started by a stone thrown into a pond They give rise to undulatory deformations of the ground Deformations of this type have been recorded when waves were passed through insufficiently resilient bodies

Surface waves fanning out from an epicentre may race round the Earth It is quite obvious that the waves moving in different directions will meet in the opposite hemisphere The point where they meet is called the antiepicentre

At present the force of an earthquake is determined with the help of a 12 point scale (Table 4) With this scale the force of an earthquake is determined not only in accordance with the shock experienced by people but also with seismograph records Shocks starting vibrations with an acceleration of less than 2 mm/sec are not noticed by people but a seismograph will record them Violent earthquakes start vibrations with an acceleration of 5 000 mm/sec^2

The tremors starting in a hypocentre are transmitted first to the epicentre where the most violent shock is felt The tremors spread out from the epicentre weakening with distance If on a map we draw a line joining places which have suffered an equal intensity of shock we will get an *isoseismal line* (Fig 98) for example a 5 point or a 4 point isoseismal line These lines form closed curves and are often very irregular for earthquake damage depends on the density of rocks (igneous cemented fissured loose and so forth) The curve of an isoseismical line therefore depends on the geological structure of the region hit by an earthquake

The greater the distance from the point of observation to the epicentre the more time is taken by the shock wave to reach that point By drawing a line through points affected by an earthquake at the same time we get a closed curve called a *homoseismal line* which in contrast to an isoseismal line is very regular because the velocity of a tremor is less dependent on the geological structure of a locality

Seismic maps are compiled on the basis of earthquake records.

Forecasting Earthquakes. One of the problems of seismological investigations is to make it possible to forecast earthquakes. Very little progress has been made in this direction although some facts indicate that a number of phenomena

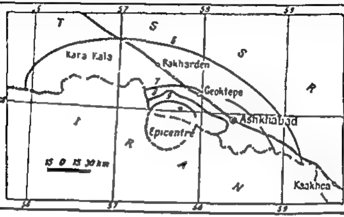

Fig. 98. Isoseismal lines of the 1929 earthquake in Ashkhabad (after G. Gorshkov)

can be accepted as heralds of an earthquake. For example, magnetic storms sometimes precede an earthquake, frequently breaking out twenty-four hours before an earthquake begins. Moreover, it is believed that an earthquake is preceded by an intensive liberation of gases from the craters of volcanoes.

Attempts have been made to use special instruments to predict an earthquake. Fairly good results have been obtained with tiltmeters which measure a rising dip on the Earth's surface with great accuracy. At every point on the Earth's surface the dip towards the horizon changes continuously. This change takes place slowly, but an acceleration is observed just before an earthquake.

Earthquake-Proof Building. Special rules for earthquake-proof building have been drawn up to counteract some of the destructive activity of earthquakes. Italy and Japan

Table 4

Force	Vibration	Acceleration mm/sec	Characteristic
1	Microseismical	<2 5	Detected only by seismological instruments
2	Very feeble	2 5 5 0	Felt only on upper floors of buildings
3	Feeble	5 10	Felt only by a few people the shock is scarcely perceptible and does not rouse fear
4	Moderate	10 25	Felt by most people in buildings and only by some in basements does not rouse fear Causes doors and windows to rattle floor beams to creak and suspended objects to swing slightly
5	Perceptible	25 50	Felt by all people indoors and by a few outdoors awakens sleepers rouses fear in some people Doors open and shut suspended objects swing violently pendulum clocks stop
6	Strong	50 100	Felt by all people indoors many rush out into the street in fear Objects fall in houses plaster cracks in walls slight damage is caused to small buildings
7	Violent	100 250	Rouses general fear and panic felt outdoors as well Makes people rush out into the street Causes bells in belfries to ring chimney pots are shaken off roofs some tiles fall to the ground relatively light damage is caused to many buildings
8	Destructive	250 00	Rouses panic Considerable damage is caused to buildings partially destroys some houses No human casualties but some people are hurt
9	Devastating	00 1 000	Some buildings are completely destroyed many are seriously damaged A few people are killed

Force	Vibration	Acceleration mm/sec	Characteristic
10	Extremely devastating	1 000–2 500	Many buildings are destroyed Many people are killed Cracks appear in the Earth's crust landslides start in the mountains
11	Catastrophic	2 500–5 000	Stone buildings are destroyed completely The concrete piers of bridges crumble iron posts are bent Wide dams and dikes are destroyed Wide horizontal cracks appear in the ground Many landslides and rock falls are started
12	Exceptionally catastrophic	>5 000	All even the seismologically strongest buildings are destroyed Horizontal and vertical dislocations appear in rocky ground numerous landslides and rock falls are started shores collapse

where earthquakes have been especially disastrous have more experience in this field than any other country It is not advisable to build houses on steep slopes, at the edges of precipices, on loose soil or on humid boggy soil First class stone material and cement should be used clay buildings are not recommended The foundations must be level the corners projections and all key sections of buildings must be strengthened with metal rods and beams Particular care must be taken over walls Experience has shown that log houses withstand earthquakes better than even the best laid brick structures The beams must be rigid and made fast to the walls The partitions must be made of light materials and properly fastened to the walls Overhanging decorations such as cornices stucco mouldings columns and balconies should be avoided because they are the easiest to destroy Multi storeyed buildings should be not erected in seismic regions because during earthquakes the upper portions of buildings vibrate more than the lower floors and are the first to collapse In the Soviet Union and other countries anti earthquake building has, in many cases proved to be quite effective

Seaquakes Seismic disturbances frequently occur on the floor of oceans The tremors start huge waves called *tsunamis* which rise to a height of several tens of metres and cause great destruction as they approach a shore and flood it A huge tsunami was started by a seaquake in Sagami Bay Japan where a section of the floor rose steeply (230 metres) and another section sank to a depth of 400 metres This gave birth to a wave of over ten metres high, which rolled shoreward (part of the water flowed towards the ocean)

During the earthquake in Chile in 1960, the tsunami that sprang up off the coast of South America rolled across the entire Pacific Basin for distances of tens of thousands of miles sweeping the shores of Japan, the Hawaiian Islands the Kuril Islands and other areas As far away as the Kuril Islands the oncoming waves reached a height of nearly two metres The coast of Morocco was attacked by tsunamis in the period from the night of February 29 to March 1, 1960 A huge sea wave that destroyed everything in its path struck the town of Agadir Tsunamis occur mainly in the Pacific but they also occur in the Atlantic and the Mediterranean

Epeirogenic Movements

Epeirogenic movements cover enormous areas of the Earth s crust They are slow and can only be detected through many years of observation For example changes have been noted in the position of coastlines with regard to the level of the sea In one area or another these movements are sometimes rhythmical i e within a certain period the coast line rises and then gradually subsides again

Ingressions (advance of the sea into river valleys) and transgressions (flooding of large land areas by the sea) are observed when a continent subsides and regressions (retreat of the sea) occur when it rises

Variations of a shore line can be established on the basis of historical geomorphological geodesic and geological facts History tells us for example that about 1 900 years ago the shore of the Bay of Naples in the region of the town of Pozzuoli began to subside and the sea covered a part of the town In the tenth century the shore rose again and the

buildings that had been submerged have survived as ruins and stand on the shore far from the edge of the water It is believed that in this area the amplitude of the shore variations was about 12 5 metres

Other evidence of uplifts of the shore includes swells on flat coasts and also terraces covered with sand rounded pebbles and remains of seashells on mountain slopes These terraces sometimes occur at an elevation of several hundred metres above sea level The amplitude of variation of the Earth s crust in any given area can be established by the height of the swells and terraces above the present sea level while the time when the terraces were formed can be determined by the fossil fauna and flora The draining of former harbours river deltas and river valleys overhanging sea coasts are also indications of uplifts Some coastal areas which had once risen high above sea level are now submerged For example the mouth of the Congo River has been traced below the level of the Gulf of Guinea for a distance of nearly 100 kilometres and at a depth of more than half a kilometre Underwater channels of the Ob Yenisei and other northern rivers have been traced over long distances

The marshy lakes along the coast of the Black Sea and the absence of shallow deltas and rivers for example in South China despite the evacuation of huge quantities of detritus are also evidence of the subsidence of coastlines

Examples of vertical variations are found in Scandinavia and Italy There are striking uplifts along the northern coast of Norway where five marine terraces have been discovered the highest of these is 176 metres above the present sea level They have been carved out on a surface polished by glaciers but are not polished themselves This shows they were formed in the post glacial period Sections of the Scandinavian coast adjoining the northern shore of the Gulf of Bothnia are at present rising at a rate of a centimetre a year Other areas where the shore line is rising include Spitsbergen Novaya Zemlya Greenland Iceland Scotland and the southern coast of the Black and Caspian seas

The reverse is taking place along the coast of South China Australia and North Africa

Slow upheavals of the Earth s crust are taking place not only in the vertical but also in the horizontal plane They

have been observed in the Alps near Lake Geneva in the Bavarian Alps in North America and other areas

In addition to the geomorphological observations described above the slow variations of the Earth s crust are measured with a fine degree of accuracy through repeated levelling Such measurements have been taken on the Caucasian coast of the Caspian in Scandinavia in North America and elsewhere

Folding and Rupturing Movements

Broken and Unbroken Bedding of Rocks The rocks of which the upper part of the Earth s crust is composed are represented mainly by stratified series that had formed primarily in water basins In a stratified formation each layer (or stratum) is separated from the others by a stratification plane The surface bounding a stratum from below is called the *foot* the surface bounding it on the top is called the *roof* In a series or bench of layers the roof of an underlying bed is at the same time the foot of the overlying bed The shortest distance between the roof and foot of a layer is called its *thickness*

When they are formed, layers of sedimentary rock are deposited on the floor of a basin horizontally or at a slight tilt In such a series each of the beds is deposited one on top of another in turn Where the conditions of sedimentation are more or less constant the stratification planes will run parallel to each other i e , the beds will be concordant

If series of strata lie parallel with one another and there is no chronological sequence between them we get a case of stratographic unconformity For example Jurassic marine rocks may lie on Devonian marine deposits whereas if the bedding had been concordant the sequence would have been Carboniferous Permian Triassic Jurassic

Stratigraphic unconformity is caused by oscillations of the Earth s crust In our example the Devonian period was followed by a rise of a submarine area of the Earth s crust which gradually subsided in the Jurassic period (Table 5)

In addition to stratigraphic unconformity there is tectonic or angular unconformity which means that rock strata lie unconformably as a result of upheavals

A disturbance in the original bedding is called a dislocation and is caused by the folding and rupturing movement of the Earth's crust

Considerable dislocations are usually found in mountainous regions In the Ural Crimean Tien Shan and Caucasian

Fig 99 Fold and rupture in Mid Paleozoic limestone

mountains for example the original horizontal or slightly tilting bedding of the rock layers has been substantially changed the gradient is steeper the strata are bent in waves and partially ruptured and along fractures they are displaced (Fig 99)

According to their nature all dislocations are divided into two types *folded* or *plicated* (continuous and undulating strata) and *ruptured* or *disjoined* (ruptured strata along some surface and in some cases subsequent displacement along the resultant fracture)

Ruptured (disjoined) Dislocations These dislocations appear as fractures from a few millimetres to tens and even

hundreds of kilometres long the strata along these fractures are frequently displaced The surface dividing ruptured beds is called a fault crevice and it may be vertical or inclined Strata may be displaced parallel to a fault crevice from bot-

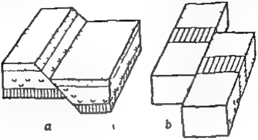

Fig 100 a—fault b—displacement

tom to top (*reverse fault*) or from top to bottom (*fault*) If the layers are displaced along the horizontal plane of a fracture they form a *displacement* (Fig 100)

Systems of parallel fractures occur frequently In some cases blocks imprisoned between faults are displaced either

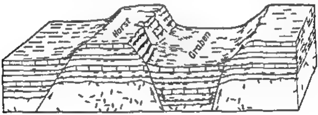

Fig 101 Horst and graben

up or down This gives rise to protuberances called *horsts* and to hollows called *trough faults* or *graben* (Fig 101) In the U S S R trough faults include Lake Baikal, whose floor has subsided by more than a kilometre Lake Teletskoye in the Altai Mountains and Issyk Kul in Kirghizia Some trough faults are extremely long Examples are the Red Sea and the Rhine rift valley, into which the Rhine river enters

and which lowered The raised or upthrown part is distinguished by a down bend of the strata the lowered part on the other hand is distinguished by an upbend The fracture surface can be very smooth (*friction plane*) or striated a fracture caused by a rupture may become filled with rock waste (friction breccia or tectonic breccia)

Folded (plicative) Dislocations In many cases strata are bent in waves and form folds The size of the e folds varies greatly

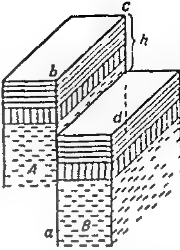

Fig 103 Elements of a fault
A—raised limb B—lowered limb ab d—fault crevice h—fault amplitude

A fold has the following *elements* (Fig 105) 1) *limbs*—two more or less even surfaces limiting the fold 2) *a curve*—the crest connecting the limbs 3) a *fold bend*—the line passing through the highest points of the crest in the curve of a fold 4) *fold angle*—the angle between the extended planes of the limbs up to their intersection, 5) *axial surface*—the surface passing through all the layers of the fold bend and dividing the fold angle in two 6) *fold axis*—the line along which the axial surface of the fold intersects the Earth s surface The axis of a fold may be either horizontal or dipped (Fig 106) if *the axis is dipped the fold sinks into the Earth s surface* in the direction of the dip

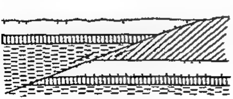

Fig 104 Thrust

By their shape and the arrangement of the rock layers in them folds are divided into two groups *synclines* and *anticlines* The former have an inverted and the latter a normal arch

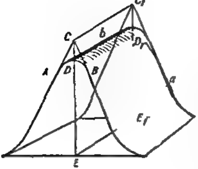

Fig 10 Elements of a fold
a—lin'i b—curve DD —fold bend ACB —f ld angle CC E E —axial surface

(Figs 107 108) Where the folds are abraded along the bends the beds in the core of a syncline are younger than in the core of an anticline

If a fold is truncated by denudation a section will show concentrically conver gent beds if the axis of a fold is long the concentres will be ellipses and if it is short they will be almost circular Folds with short axes (2 1 5 1) are called *brachyaxial folds*

If an anticline is complicated by small folds it is called an *anticlinorium* a syncline similarly complicated is called

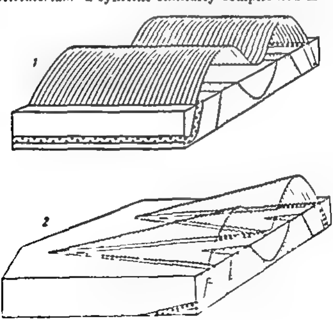

Fig 1 Folds with non dipping (1) and dipping ( ) axes

a *synclinorium* A fold is from a few centimetres to several tens and hundreds of kilometres wide

By the position of their axial surface folds are classified as follows erect or upright—if the axial surface is vertical or nearly vertical, oblique—if the axial surface is in

Fig 107 Folds in limestone

clined and the limbs dip in different directions overturned if the axial surface is inclined and the limbs dip in one direction only recumbent—if the axial surface is horizontal (Fig 109)

There is a quaquaveral structure called a *diapir fold* or fold with a diapiric core It resembles a dome and the rocks in its core are lithologically different and older than the surrounding rocks A diapiric structure is usually due to the formation of a gently sloping anticline when a mobile plastic core consisting of rock salt for example partially pierces and deforms the overlying layers This type of structural feature is widespread in oil regions

The form and size of the folds depend on a number of factors the petrographic composition of the rocks, the thick

Fig 108 Syncline (a) and anticline (b)

ness of the layers the direction and force of the pressure developed by mountain making processes The most intensive folding is thus observed where the rock layer thins out The folds in argillaceous and marly rocks are usually more regular than those in limestone

There is a flexed strata which is the transitionary form between folded and disjoined dislocations This transitionary form is called a *flexure* In the limbs of a flexure the rocks are bedded horizontally while between them there is a sheer almost vertical dip (Fig 110) Consequently one portion of

Fig 109 Folds
a—erect b—oblique —overturned d—recumbent —inverted

a layer is either raised or lowered in relation to another The displacement may be so considerable that the layer breaks at the bend and the flexure becomes a fault Flexures occur frequently in plateaus These are either brachy folds or cupolas All the above mentioned folds occur singly amidst horizontally bedded rocks Long (linear) folds develop in geosynclinal areas frequently occur in groups and are intricately shaped they are grouped close together in narrow strips hundreds of kilometres long (the Alps the Carpathians the Cordilleras)

Fig 110 A flexure

Position and Measurement of Beds An idea of the elements governing the occurrence of a bed has been introduced to show its position accurately in space These elements determine the position of a bed in relation to its dip and the four cardinal points of the compass

The elements of a bed s position are the strike, the dip and the dip angle

By *strike* we mean the azimuth* of the line of strike The *line of strike* is any horizontal line in the plane of a stratum The *dip* is the azimuth of projection of the dip line on a horizontal plane The *dip line* is the plane passing through the plane of a stratum in the direction of its maximum angle

From the above definitions it follows that it is possible to draw any number of strike and dip lines in a plane of a stratum and that all the strike lines as well as all the dip lines will be parallel to each other The dip lines are perpendicular to the strike lines

The *dip angle* is the angle a stratum is inclined from the horizontal (Fig 111)

The elements of a bed s position are determined with a dip compass This compass has three features that distinguish it from an ordinary compass

1 It is mounted on a rectangular support so that its 0 180 (N S) diameter is parallel to its long sides

2 The limb is graduated counter clockwise East and West are also arranged counter clockwise the former is on the left of north the latter on the right The reason for this is to allow the azimuth value to be determined directly from the reading of the north end of the magnetic needle

With a dip compass the azimuth is measured northward from the direction to be determined and must therefore be

* The azimuth is the angle between a line directed northward and another passing clockwise through a given direction It is measured in degrees (0 360) and is determined with a compass The magnetic azimuth i e the angle between the direction towards the magnetic pole and a given direction is also measured A correction that takes into account the magnetic deviation i e the angle between the direction to the magnetic pole and the geographic pole is made to obtain the true azimuth" An east deviation is one in which the direction towards the magnetic pole is deviated eastward from the geographic pole the reverse of this will be a west deviation

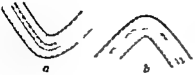

Fig 108 Syncline (a) and anticline (b)

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a—erect, b—oblique, c—overturned, d—recumbent, e—inverted

a layer is either raised or lowered in relation to another. The displacement may be so considerable that the layer breaks at the bend and the flexure becomes a fault. Flexures occur frequently in plateaus. These are either brachy folds or cupolas. All the above mentioned folds occur singly amid horizontally bedded rocks. Long (linear) folds develop in geosynclinal areas, frequently occur in groups and are intricately shaped; they are grouped close together in narrow strips hundreds of kilometres long (the Alps, the Carpathians, the Cordilleras).

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measured counter clockwise The zero position of the limb is set in the direction to be determined This will make the north end of the magnetic needle stop at the point indicating the azimuth of the looked for direction

3 A plumb is suspended from the needle of a dip compass The graduations of the plumb are on the bottom of the com

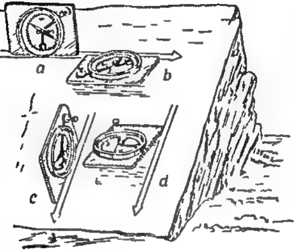

Fig 111 Measuring the dip and strike of a rock layer with a dip compass

pass case (0 90 in both directions) The plumb points to zero when the compass is in a vertical position

The bed strike is determined as follows

1 The compass is placed vertically with the long side of the support on the surface of a bed the plumb hanging down The vertical position of the plumb is determined by allowing it to oscillate freely A position is selected for the compass in which the plumb stands at zero in this position the side resting on the rock bed will indicate the strike line

2 The compass is then placed in a horizontal position with its long side on the strike line the magnetic needle released and the reading of its northern tip taken This read

ing will be the strike (the azimuth of the strike line) The compass must be placed horizontally so that both ends of the released magnetic needle are level with the limb

The bed dip is determined as follows

1 The compass is placed vertically with its long side on the surface of the bed, the plumb hanging freely This side must be directed approximately down the dip of the bed A position must be found for the compass in which the plumb will show the maximum deflection When this position is found the long side on which the compass rests will coincide with the dip line

2 The compass is then placed on the bed surface so that one of the long sides of the support coincides with the strike line and the zero on the limb or letter N is alligned with the dip of the bed in the direction of the dip line The short side of the support is lifted slightly (without moving the compass) and the compass is brought into a horizontal position The northern tip of the released magnetic line will indicate the dip (the azimuth of projection of the dip line to the horizontal)

The dip angle is determined simultaneously with the dip line inasmuch as the maximum deflection of the plumb shows the looked for angle

The strike and dip with the exception of the angle (in degrees) are recorded together with the point of the angle (NE, SE SW or NW) This is done to check and facilitate indoor analyses of data obtained in the field

The following is a sample of how the elements of the bed position are recorded Strike SW 225°, dip SE 135° $\angle 32°$

If the measurements are made correctly there will be a 90° difference between the strike and dip If there is a considerable (2 3) deviation from this value the measurement should be repeated

Periods of Orogenesis When tectonic disturbances of the Earth s crust are studied it is very important to establish the age of a disturbance and also the area affected by it In some areas deposits of the same age lie horizontally in others they are folded In one and the same area, deposits of different ages may be dipped at different or unconformable angles This shows that disturbances do not take place everywhere or continuously but at more or less definite intervals (Table 5)

Table 5

Era (group)	Characteristics	Period (system)	Characteristics
Archean	Igneous and repeatedly metamorphosed rocks No plant or animal remains Marbles (metamorphosed limestones) and graphites testifying to the presence of an organic kingdom occur in the upper level deposits		
Proterozoic	Igneous and metamorphosed rocks Scanty but identifiable remains of lower invertebrate marine animals and algae		
Paleozoic	Non metamorphosed sedimentary rocks Invertebrate animals predominate in the era appearance of armoured ganoid and dipnous fish Invertebrates and lower vertebrates appear on land Lower plants—lycopods equisetums ferns—develop rapidly Mountain building at the beginning and end of the era	Cambrian	Land fauna and flora unknown Most important guide fossil—trilobite (of the order of crustaceans) Sponges starfish worms inarticulate brachiopods bivalve mollusks and cephalopods appear Local glaciation Weak volcanic activity
			Epistoparia trilobites and articulates (brachiopods with a calcerous shell)

	Ordovician	develop in the sea giant marine arthropods (gigantostracans) appear groups of *corals*—tabulate corals bryozoans and cephalopods (nautiloids)—begin to develop rapidly at the close of the period First arthropods (*myriapods scorpions*) appear on land
	Silurian	Proparian trilobites *corals crinoids* (sea lilies) as well as orthoceratites and nautiloids from the group of cephalopods develop rapidly Further evolution of sea urchins brachiopods and ammonoids Armoured fish appear Transgression of the sea at the beginning and regression at the end of the period Intensive volcanic activity Caledonian mountain building
	Devonian	First ganoid and dipnous fish appear in the sea *Armoured fish and ammonoids* develop rapidly Abundant (lower) vegetation on land Repeated transgressions and regressions *Tropical climate in the higher* latitudes

Continued

Era (group)	Characteristics	Period (system)	Characteristics
Paleozoic		Carboniferous	Armoured fish and trilobites die out On land—luxuriant development of lycopods equisetums and ferns First giant amphibians and reptiles appear Numerous insects and spiders Coal deposits accumulate Intensive volcanic activity Tropical climate in the higher latitudes Beginning of Hercynian mountain building Glaciation of the southern continents at the close of the period
		Permian	Trilobites tetracorals and so on disappear from the sea Ganoid fish and ammonoids develop Dipnoi (stegocephalians and cotylosaurs) flourish on land Considerable regressions and development of volcanic activity Close of the Hercynian mountain building period (during which in particular the Ural and Tien Shan systems appeared) Intensive glaciation in equatorial regions and accumulation of salt in the temperate latitudes

Mesozoic	Deposition of sedimentary rocks Ammonites amphibians (dipnoans) and reptiles flourish in the sea First bony fish On land—first birds butterflies and flowering plants	Triassic	Ancestors of modern corals and belemnites appear in the sea On land—extinction of stegocephalians and cotylosaurs and the appearance of reptiles—dinosaurs turtles crocodiles and therapsid reptiles Appearance of lower mammals bony fish and long tailed crayfish Considerable regressions of the sea Subtropical climate Vast deserts
		Jurassic	In the sea—extinction of orthoceratites evolution of ammonoids into ammonites Appearance of asymmetric sea urchins crabs On land—extinction of therapsid reptiles giant reptiles flourish appearance of frogs pterosaurs primitive birds and butterflies Large transgressions of the sea Cimmerian mountain building differentiation of climatic belts

Continued

Era (group)	Characteristics	Period (system)	Characteristics
Mesozoic		Cretaceous	In the sea—extinction of ammonites and belemnites at the close of the period On land—appearance of salamanders modern crocodiles and python like serpents Extinction of giant reptiles—dinosaurs ichtyosaurs and pterosaurs Appearance of primitive mammals and flowering plants Violent transgression in the middle of the period
Cenozoic	Deposition of sedimentary rocks Tremendous eruptions of lava Immense transgressions and regressions Gradual formation of modern continents Alpine mountain building	Paleogene	In the sea—bony fish flourish Molluska approach their modern form On land—ancient serpents and lizards still in existence Mammals acquire gigantic sizes Appearance of prosimians cetaceans and edentates The climate has been differentiated Alpine mountain building begins

Neogene	Marine fauna reaches almo t modern forms Appearance of numerous pecies of ea mammals Giant mammals begin to die out on land Intensive development of ungulates proboscideans and carnivores Appearance of anthropoid apes End of Alpine mountain building
Quaternary	Unque tionable igns of man s existence appear at the beginning of the period Continents and eas acquire their modern outlines Sharp drop of temperature and sustained glaciation alternating with interglacial epochs

In the history of the Earth we distinguish four basic periods of orogenesis

1 Period of *Alpine* folding Mesozoic (Jurassic Cretaceous) folding—from the Tertiary period down to our day

2 Period of *Hercynian* folding Carboniferous Permian period

3 Period of *Caledonian* folding Silurian period

4 Period of *Pre Cambrian* folding repeatedly in the course of the Pre Cambrian period

A mountain system is attacked by denudation even while it is being formed That is why we find the tallest peaks (7 500 8 800 metres) in young mountain systems that were formed at the close of the Tertiary period (Alpine folding) These mountain systems encircle the Pacific Ocean and also stretch latitudinally from the Atlantic to the Pacific along the southern margin of Europe and Asia (Cordilleras Andes Caucasus Altai Pamir Himalayas)

In the mountain systems that arose at the end of the Paleozoic period (Hercynian folding) the peaks hardly reach 1 500 2 000 metres The great height of the Tien Shan which is also a Hercynian system is due to the arched uplifts that took place in the Alpine period of mountain making And lastly none of the peaks in the mountain systems dating from the Caledonian period (the mountain systems in Norway and Scotland) rise higher than 1 500 metres

Principal Geological Structures of the Earth s Crust The crustal movements described above lead to changes in the structure of the Earth s crust and in the relief of the Earth s surface The geological structures distinguished in the Earth s crust are platforms geosynclines and folded zones

Platforms are rigid and stable areas subject mainly to relatively light oscillatory movements

There are two stages in the structure of a platform the lower stage or foundation consisting of thick series of greatly dislocated and metamorphosed Pre Cambrian rock the upper stage is several tens or hundreds of metres thick and usually consists of horizontally bedded marine sediments of Paleozoic Mesozoic and Cenozoic rock The stratigraphic unconformity of the deposits of the upper stage shows that there is epeirogenic activity in these areas Local folding,

manifested in the formation of domes and undulating folds with gently dipping limbs sometimes occurs in the sedimentary cover

The foundation of the platform is alternately raised and lowered The raised foundation blocks are called *anteclises* and the lowered blocks *syneclises* Sections of the platform with foundation outcrops are called *shields* The latter are thus the most rigid portions of the platform in the post Pre Cambrian period they did not subside but on the contrary underwent positive vertical movements (uplifts)

The platforms on the surface of the Earth include the Russian the Siberian, the Australian and the North African In every platform there are shields, for example the Baltic and Ukrainian shields in the Russian platform the Anabar Aldan and Yenisei shields in the Siberian platform, and the Canadian shield in the Canadian platform

Folded zones form in geosynclinal zones and are areas of the Earth s crust where folded beds are exposed on the surface *Geosynclines* are the most mobile sections of the Earth s crust They are affected by intensive variations and therefore have favourable conditions for the accumulation of thick (several thousand metres) sediments These sediments are folded ruptured and greatly dislocated by the folding movements of the Earth s crust During these processes magma penetrates into the sedimentary series through fractures and weakened zones in the crust and forms various intrusions in them

The enormous pressure caused by the folding processes and also the penetration of magma subject the rocks in a geosyncline to intensive metamorphism so that they gradually lose their plasticity and ability to fold Thus through orogenesis a geosyncline is replaced by a rigid and immobile folded system which may be described as a young platform In a geosyncline orogenesis ends with a general epeirogenic uplift of the area and the newly formed folded system turns into a mountain structure The destruction of mountains by exogenous forces on the one hand and the loss of tectonic mobility on the other ultimately transform folded terrain into a platform

The following are indications of a folded region

a) a thick series of sedimentary and igneous rocks

b) intensive folding
c) abundance of intrusions and minerals
d) metamorphism of rocks

The Ural Tien Shan Altai (Hercynian structures) Crimean Caucasian Carpathian and Pamir (Alpine structures) mountain systems are examples of folded regions formed at different times

Big mountain systems are usually characterised by complex combinations of rupture and plicative dislocations and the most diverse folds and faults may be observed in them *In some cases however one form of dislocation predominates* Where the disjoined form predominates we find mountains with a block structure, if fold dislocations predominate the structure of the mountains will be folded

Compared with tectonic formations some of which stretch for tens and hundreds of kilometres composite (volcanic domes barkhans dunes) and also denudation (monadnocks formed through the geological action of wind and water) mountains are very small

In conclusion it must be noted that the tectonic processes which formed the world s greatest mountains have not ended Geosynclines i e the most mobile areas exist and continue to develop and emerge as is evidenced by the regions of subsidence where intensive sedimentation is proceeding An example of a developing geosyncline is the section of the Pacific Ocean embracing the Kuril Islands Japan the Malay Archipelago and so on An archipelagic (insular) pattern indicates a basin accumulating sediments deposited in inter island depressions through the ablation of material from the islands Other indications of a developing geosynclinal basin are the scale of the variations manifested by different signs in different parts of the basin intensive volcanic activity and intense seismicity All these features manifest themselves in the West Pacific

METAMORPHISM

By metamorphism we mean a change in the constitution of sedimentary and magmatic rocks under the influence of the internal processes in the Earth's crust. The principal agents are heat, directed pressure and pneumatolysis (the processes by which minerals form with the participation of gases and solutions released by magma). Metamorphism alters not only a rock's structure and texture but also its mineral composition.

Metamorphic rocks are schistose and granular, this being due to their recrystallisation under great heat and foliation under high pressure. For example, during mountain building processes, the rocks experiencing great directed pressure fold, crumple and wear away, with the result that they become laminated, which is quite different from the banding or lamination of sedimentary rocks.

The two basic forms of metamorphism are: *dynamic* (due to pressure) and *thermal* (due to heat).

Dynamic metamorphism is observed, for example, during fold forming processes at depths where the temperature is at least 200-300° C. Thermal metamorphism usually manifests itself where primary rock comes into contact with intrusions (Fig. 112). Another name for thermal metamorphism is *contact* metamorphism.

Where contact metamorphism takes place, the invading molten magma, which requires a long time to chill, acts on the sedimentary series in all directions, melting it at the points of direct contact and transmitting its heat (800° C at the point of contact) over large areas. New minerals that form a contact aureole are developed through the mixing

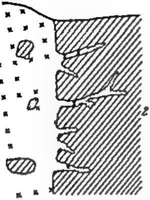

Fig 112 Contact between intrusive (1) and sedimentary (2) rocks

of the minerals of the molten magma with material from the melted sedimentary rocks The number of these new minerals depends on the mineral content of the magma and the sedimentary series it is invading

For example when granite magma comes into contact with sedimentary quartz sand and sandstones hardly any new minerals are formed But when it invades limestone series the new minerals that form in the contact aureole are alien to both the magma and the limestone A series of transitional zones appear between the granite magma and the limestone and the farther this series is from the granite mass the greater is the number of basic rocks represented in it Lastly pure limestone recrystallises and turns into marble in areas where melted limestone does not mix with molten magma In the Urals where granite comes into contact with olivines the latter turn into hydrate rich talc and chlorite schists

As gases vapours and partly water solutions move through fissures in the colder parts of the lithosphere and impregnate large areas of the Earth s crust they cause rocks to go through a transformation cycle known as *pneumatolytic* metamorphism if the agents are hot gases and vapours without the participation of water or *hydrothermal* metamorphism if the process involves superheated mineralised water

Heat also becomes involved in the process if under the weight of new sediments or as a result of tectonic forces a series of accumulating rocks gradually subsides into deeper zones of the Earth s crust In this case there is no contact between cold sedimentary series and invading magma A sedimentary series covering a large area sinks uniformly into a region of intense heat As they sink the sedimentary beds first turn into a plastic and then possibly into a fluid state *Regional metamorphism* is manifested here

Although at small depths the hydrostatic pressure is not very great in the Earth's crust it becomes enormous at a depth of 10-20 kilometres. On the average a rock column of five metres (with a base area of one square centimetre) produces a pressure of one atmosphere. Therefore at a depth of 5 000 metres the pressure must be 1 000 atmospheres and at a depth of 25 000 metres 5 000 atmospheres. Combined with high temperatures (up to 1 500° C) this colossal pressure causes basic changes in the state of rocks making them plastic. Reciprocally displacing each other, these rocks at the same time grind each other into fine particles (this process is called melonitisation or grinding). A clearly defined schistosity appears in rock its mineral components being arranged in parallel lines.

As we have already stated near the surface of the Earth temperature and pressure do not play the same role as at great depths. That is why the region of rock metamorphism linked up with the sinking of sedimentary series into the interior of the Earth, is divided into three zones: the upper zone or epizone (zone of superficial transformation), the middle zone or mesozone (zone of medium transformation) and the bottom zone or hypozone (zone of abyssal metamorphism).

In the *epizone* the temperature and pressure are relatively low. The metamorphic rocks that form in this zone have a clearly defined schistosity and the minerals are lamellar and scaly, their long axes being at the normal to the acting force.

In the *mesozone* the temperature and pressure are higher providing the conditions for deeper recrystallisation of sedimentary rocks. Mechanical disturbances in the form of fissures, faults and so on are also observed. The rocks developing in this zone are mica schists, amphibole schist and gneisses. The first two include feldspar in addition to mica, hornblende predominates in the latter. Crystalline schists, which are metamorphosed more than any other schists frequently occur in this zone.

In the *hypozone* the temperature is extremely high and the pressure tremendous. In this zone rocks undergo very deep recrystallisation and augite and olivine are the most widespread of the neocrystallised minerals.

If this subsiding sedimentary series is invaded by magma the above transformation sequence will be considerably altered In addition to the influence of pressure there will be phenomena engendered by contact metamorphism A description of the principal metamorphic rocks will be found in the section entitled "The Lithosphere"

Dynamic metamorphism which is called forth by mountain building processes is also known as dislocation metamorphism

BRIEFLY ABOUT THE EARTH S AGE

Throughout history man has been attempting to determine the Earth s age In ancient times the results of these attempts differed greatly In the East (China and Japan) for example the world s age was given as several tens of millenniums and by some scholars as over 100 000 years In the Mediterranean countries the Earth s age was determined as being about 5 000 years (before our era) This figure was accepted by the Christian world throughout the Middle Ages

All the old concepts were upset through investigations of fossil fauna and flora Paleonthologists who found changes in numerous generations of the animal kingdom came to the conclusion that it required much longer than a few hundred thousand years for life to develop on our planet

Attempts were made to determine the time that was taken by some of the processes on Earth It was surmised for example that originally the water in the ocean was fresh The reason—it derived from atmospheric precipitation which contains practically no salt at all Today ocean water is quite saline averaging 3 5 grams of salt per litre This salt is brought from land by rivers whose waters have a considerable content of minerals Ocean water evaporates and is returned to land as precipitation by virtue of which the rivers carry huge quantities of salt to the ocean year after year The quantity of salt annually carried by rivers can be calculated Moreover we know how much water there is in the ocean It was therefore not difficult to compute that it took the ocean approximately half a million years to reach its present level of salinity

This method of computation is not faultless because a) we do not know what the initial salinity of the ocean was and b) we take no account of the physical and chemical processes taking place in ocean water the vital activity of organisms in particular Marine dwellers build their skeletons from the salt in the sea, and they accumulate salt in their bodies There is for instance very little iodine in sea water, yet some algae concentrate it so intensively in their bodies that it is obtained on an industrial scale from their remains

The figure 500,000 years produced by such a simple arithmetical calculation, as the Earth s age cannot therefore be considered accurate

In some areas we find varved clays which are so far as we know, silty sediments deposited in closed reservoirs The varved character of these deposits is due to the alternation of thin (several millimetres) layers of silt and fine sand It was suggested that the layers of silt were deposited during low water seasons and the coarser material (sand) when ice thawed precipitation increased and turbid water flowed into lakes Each pair of layers thus represents the result of a years s accumulation of sediments The thickness of the layers has been measured Knowing the thickness of the entire deposit and dividing this thickness by the thickness of a pair of layers we get a figure showing the time it took a particular deposit to accumulate For some lakes the figure was 15,000 20,000 years

But this figure only concerns one of the latest periods of the Earth s life when sediment filled reservoirs were already in existence These reservoirs appeared after the retreat of a huge ice sheet from the territory of Eastern Europe We thus only have a characteristic of a very short period of the Earth s life

A radioactive method of determining the Earth s absolute age was used in recent decades following the discovery of radium This method is founded on the fact that the atoms of some unstable elements, chiefly uranium and thorium disintegrate continuously, forming atoms of other elements The stable end products of decay are helium gas and inert metal lead The helium volatilises the lead accumulates

The age of a mineral can be computed by finding its relative content of a radioactive element and lead or helium The

same concerns the rock from which the mineral has been extracted. This holds the key to the approximate age of the Earth's crust.

Most geophysicists now agree that the Earth has existed as a planet for 3,000-6,000 million years. By this method it has been established that the Earth's crust is 3,000-4,000 million years old. In addition, the radioactive method has been used to determine the duration of various periods of the Earth's development. Much has been done in this field by the Soviet scientists V. Vernadsky, K. Nenadkovich and V. Khlopin.

The time it took various rocks of the Earth's crust to form cannot always be expressed in absolute figures. It is more usual to determine their relative age. This relative age is found by dividing the Earth's history into periods of the existence of definite groups of flora and fauna. A study of fossil fauna and flora showed a gradual succession of forms in time and that this succession is governed by a definite process of progressive development of organisms. The most primitive organisms occur in the oldest layers. Many fossils occur in beds deposited at definite periods and do not reappear in the Earth's history. They are therefore called *guide fossils*.

By establishing a definite succession of organic forms scientists have been able to distinguish the corresponding periods in the Earth's history. The basic units in relative geological chronology are: an *era*, embracing a major period of the Earth's existence, and a *period*, which is a part of an era. In its turn the period is divided into smaller units (epochs and ages).

Series of sediments containing organic remains were deposited on the Earth's surface or in reservoirs during each era. A series of sediments deposited during a definite era is called a *group* of sediments, and a series deposited in the course of a definite period of the Earth's life is called a *system*.

A series of successive eras is thus distinguished in the Earth's life. The oldest is the *Archean* era, when no plant or animal organisms could exist. It is followed by the *Proterozoic* era, during which the simplest forms of life appeared. The next is the *Paleozoic* era with its abundance of lower types of animals and plants. The *Mesozoic* era, the next in

Chart of Geologic Time

Table 6

Era (group)	Index	Period (system)	Index	Epoch (division)	Index
Cenozoic	Az	Quaternary (1 000 000)	Q	Holocene Pleistocene	Q_2 Q_1
		Neogene (27 000 000)	N	Pliocene Miocene	N_2 N_1
		Paleogene (32 000 000)	Pg	Oligocene Eocene Paleocene	Pg_3 Pg Pg_1
Mesozoic	Mz	Cretaceous (70 000 000)	Cr	Upper Lower	Cr Cr_1
		Jurassic (25 000 000)	J	Malm Dogger Lias	J_3 J_2 J_1
		Triassic (30 000 000)	T	Upper Middle Lower	T_3 T T_1
Paleozoic	Pz	Permian (2, 000 000)	P	Upper (Tatar) Lower (Kazan)	P_2 P_1
		Carboniferous (55 000 000)	C	Ural Moscow Dinantian	C_3 C_2 C_1
		Devonian (55 000 000)	D	Upper Middle Lower	D_3 D_2 D_1
		Silurian (120 000 000)	S	Upper (Gothland) Lower (Ordovician)*	S_2 S_1
		Cambrian (80 000 000)	Cm	Upper Middle Lower	Cm_3 Cm_2 Cm_1
Proterozoic	Pt	The subdivisions are of local importance (1 500 000 000 2 000 000 000)			
Archean	A				

* Now classified as an independent period

chronology witnessed the evolution of highly organised animals and plants which differed greatly from present day fauna and flora The latest is the *Cenozoic* era in which animals and plants developed into the forms we know today

We shall not stop to detail the Archean and Proterozoic eras but shall note that the Paleozoic era has five main periods *Cambrian Silurian Ordovician Devonian Carboniferous* and *Permian* the Mesozoic era has three *Triassic Jurassic* and *Cretaceous* The Cenozoic (Neozoic) likewise has three *Paleogene Neogene* and *Quaternary* (Anthropogene)

The names of the divisions of the Paleozoic era (Cambrian Silurian Devonian and Permian) derive from the localities where the corresponding deposits containing characteristic fossils were first discovered The Carboniferous was so named to designate the period of the coal measures such as the Donets Moscow and other basins formed by the luxuriant vegetation that appeared on the Earth for the first time

The Triassic period of the Mesozoic era is so called because the lithological composition of the rocks allows the deposits to be divided into three different formations the Jurassic period gets its name from the Jura Mountains which extend between France and Switzerland where the corresponding deposits were first described Lastly the Cretaceous period is named after chalk which was deposited in large quantities for the first time in this period

The periods of the Cenozoic era were named after the animal kingdom of the era In the Paleogene we find the remains of vertebrates that are now extinct In the Neogene the vertebrates approached the form of modern mammals And lastly the Quaternary (Anthropogene) is characterised by the appearance of man A brief description of the eras and periods is given in Table 5

The basic age divisions (eras groups and periods systems) are usually given in abbreviated form by indexes of the first letters of the Latin name of the given division A division smaller than a period is designated with a figure written on the right of the index of the corresponding period Thus the index of the Carboniferous system is C of its lower division C_1 If the division is further subdivided into stages or formations the latter are designated as follows C C_1 C_1 and

so forth the figures corresponding to the sequence of sedimentation i e C^2 is older than C_1^2 but younger than C_1

The indexes of eras, periods and their division into epochs are given in Table 6

HYPOTHESES ON THE DEVELOPMENT OF THE EARTH S CRUST

The approach to the problem of the formation of the Earth s crust has been different at different times depending on the state of knowledge

The Kant Laplace nebular hypothesis of the origin of the Earth influenced the tectonic views of geologists at the beginning of the nineteenth century In 1829 Elie de Beaumont advanced his contraction hypothesis of the formation of the Earth s crust This hypothesis was based on the assumption that as the core of the Earth cooled, the hard outer crust followed suit crumpling and forming folds or mountains

It was warmly received by geologists and was the dominant tectonic hypothesis of the nineteenth century

Some followers of the contraction hypothesis have computed how much the strip of the Earth s crust now occupied by the Alpine mountain system had contracted Albert Heim for instance gave the figure as 120 kilometres and later increased it several times Other scientists suggested that this strip must originally have been more than 2 000 3 000 kilometres wide

E Haug took the contraction theory a step further He applied the concept of geosynclines (tectonic troughs where intensive sedimentation takes place) advanced by James Dwight Dana, Harry Fielding Reid and other geologists to explain some of the phenomena observed when mountain systems are studied

His theory is that when continents subside, the tectonic troughs (geosynclines) usually situated between them are compressed from two directions and that this leads to the formation of a folded zone along either side of the trough The folds are tilted towards the continental area (platform) adjoining them For example, the Bethian Cordilleras (in the Iberian Peninsula) the Pyrenees the Alps the Carpathi

ans the Balkan and the Caucasian Mountains are tilted to the north while the Atlas Mountains (in Africa) the Apennines the Dinaric Alps and the Hellenides (in the Balkan Peninsula) the Taurus Mountains (in Asia Minor) and the Iran Mountains are tilted to the south

These ideas were further developed by Leopold Kober who compiled a diagram showing the structure of all continents and ocean troughs As his basic units Kober used orogenic zones or orogens into which geosynclines are transformed and kratogenic fields or kratogens—a specific tectonic type of stable crystalline structures (shields plates or platforms according to some authors) Contrary to some followers of the contraction theory (Eduard Suess for example) who flatly disclaim the possibility that large areas of the Earth s crust can be vertically uplifted Kober attaches great importance to these movements They are now called epeirogenic (continent making) or geocratic (land increasing) if they are directed upwards and thalassocratic if they are directed downwards and are accompanied by an advance of the sea

New ideas were put forward at the close of the nineteenth century On the one hand these ruled out the processes of compression and on the other supplemented and supported the contraction theory First of all mention must be made of the isostasy theory (teaching on equilibrium) which was developed by Clarence Edward Dutton and supported by Marcel Alexandre Bertrand I Lukashevich and others According to this theory the Earth s heterogenous crust which consists of sections of different mineral composition and consequently of different density lies on liquid magma These separate sections are therefore submerged in this magma to various depths depending on their thickness and density in the same way as objects of various density float on water The surface of the various sections was originally uneven Denudation smoothed out this unevenness and moved masses of minerals from elevated to lower lying areas This caused a change in the load made the lightened areas more buoyant and submerged the overloaded areas deeper into the magma Fractures appeared between the areas set in motion Magma rose along these fractures and penetrated rocks increasing their weight and disturbing

their equilibrium This theory was sharply criticised the main point being that it reduced the entire geological process to a one sided trend asserting that displaced masses can only move in one direction because when masses are displaced they cannot return to their original position In other words, one area will be continuously losing its load and rising while another will be sinking Once very widespread this theory is now accepted with substantial reservations

V Obruchev said We can assume that the Earth s history consists of long evolutionary periods in which the struggle between compression and expansion does not cease but weakens and manifests itself in oscillatory movements and in isostatic compensation of equilibrium disturbances arising in the revolutionary periods Alternating with evolutionary periods the latter are shorter and are marked by an intensification of the struggle between compression and expansion which is solved spasmodically and leads to sharp changes in the surface relief Each period may be called a cycle and consists of a number of phases corresponding to the temporary triumph of compression or expansion

This alternation of compression and expansion has been named pulsation and the hypotheses are therefore called pulsation hypotheses

A number of theories deal specifically with the horizontal drift of continents The most typical of these is the theory of the equiponderant wandering of granitic continents on a basaltic substratum Proposed by Alfred Lothar Wegener this theory states that originally the granitic shell developed as a thin uniform layer over the entire surface of the Earth but in the Paleozoic era centrifugal forces collected it together in one continent At a later era the same forces split this continent and scattered it over the surface of the planet forming the present continents and islands

The general picture of the drift according to this theory is as follows The two Americas broke away from Africa and Europe and were moved far to the west This brought the Atlantic Ocean into being while the resistance of the basaltic substratum to this westward drift gave rise to the Andes and the Cordilleras Africa broke away from Asia partly turning south in a clockwise direction leaving space for the Indian Ocean Australia and Antarctica broke

away from Africa and Asia, drifted south and moved apart. The pressure directed from the poles to the equator caused mountain systems to rise in the continents in the expanse from the Atlantic to the Pacific. The insular arcs in the Atlantic (the Antilles and South Hawaiian Islands) and the Pacific (the Aleutians, the Kurils, Japan, the Philippines and the Sunda Islands) are fragments of continents that had lagged behind in the course of the drift.

V. Belousov listed a number of considerations that disproved the drift theory. Thus the Wegener hypothesis takes no account at all of such important tectonic factors as oscillatory movements. Neither does it explain the phenomena of intermittent folding. If the basaltic substratum is softer than the granitic continent, then it and not the floating continent should fold, and if it is harder it should remain motionless. Further, the entire history of the Earth shows that though different in structure the oceans and continents are identical geotectonically. This unity is excluded by the continental drift theory. Lastly, the source of the forces moving the continents is unknown: neither tidal attraction nor centrifugal forces are sufficient to explain this movement.

An attempt to clarify the latter problem was made by M. Bogolepov, who came forward with the idea that the same laws govern the movement of gases and liquids as cyclones. Liquid magma cannot remain motionless eternally. When it is set in motion it will migrate in accordance with the law of cyclones and anticyclones and its movement is transmitted to the Earth's crust. An examination of the geomorphological forms of the Earth's surface (the outlines of continents and insular arcs) will quickly show that in their arrangement there is a regularity that reflects the character and forms of subcrustal cyclonic and anticyclonic movements. But even these clarifications cannot eliminate other weaknesses of the continental drift theory.

John Joly advanced a hypothesis on the significance of radioactive processes in geotectonic processes. It was supported by A. Arkhangelsky and others. Like Wegener, Joly assumes that the continents are a sialic (granitic) mass with a density of 2.7 floating on a simatic (basaltic) bed whose density is over 3.0. Continents with a thickness of up to

35 000 metres are submerged in the basaltic bed to a depth of 30 000 metres in the same way as icebergs are submerged in the ocean The Pacific Ocean has no granitic layer while in other oceans the layer is very thin The continents remain immobile as long as the basaltic bed is hard But the heat from radioactive decay acts on this bed

Joly has calculated that the heat the Earth loses through radiation is compensated at a certain depth by an inflow of heat of radioactive origin while still deeper at approximately 48 000 metres the inflow of radioactive heat exceeds the heat lost through radiation and it gradually accumulates In the course of a period of 33 to 50 million years the temperature of the basaltic bed at this depth rises to melting point This increases the volume of the basaltic layer and consequently that of the Earth as a whole The result is that the hard crust is deformed and ruptured particularly on the floor of oceans where enormous quantities of lava issue The density of the basaltic bed decreases when its volume increases and consequently the granitic material submerges deeper in it and a transgression of the sea takes place on the surface Finally the liquid basaltic bed is set in motion in a westerly direction by the tidal forces of the Moon and Sun and it carries the continents along with it But during this drift of continents the sections of the basaltic bed that had lain beneath them sink below ocean level and gradually harden as they cool Their density increases and volume decreases The Earth s radius contracts the crust shrinks the continents regain their former level and the sea retreats Mountain making processes are started along the margin of continents under the enormous pressure of the ocean floor and then a stage of rest longer than the continental drift phase sets in Once again heat begins to be accumulated the basaltic bed melted and so forth

The Joly hypothesis links together reciprocally dependent phenomena and divides our planet s history into revolutionary (epochs of the movement of continents) and evolutionary (epochs of rest) stages Endogenous forces predominate during the revolutionary stages and exogenous forces during the evolutionary stages These stages form a cycle that has repeated itself over and over again in the history of the Earth The external harmony and integrity of the Joly hypothesis

have attracted many geologists to it. Essentially, however, Joly's only service is that he drew the attention of scientists to radioactive decay as a unique source of heat.

The basic objection to the Joly hypothesis is that the Earth's history consists not of a simple alternation of events but of an intricate regular process of development progressing in a definite direction. Joly does not explain all the structural features of continents and mountain ranges. His calculations are arbitrary, poorly supported by facts, and have been disproved.

A new radiomigration hypothesis was recently formulated by V. Belousov. He regards radioactivity as the key power factor and assumes that the distribution of radioelements in the Earth is irregular and changing. The subcrustal heating of the rock mass by radioactive decay causes it to expand at a certain depth and this explains the greater dynamics of vertical tectonics. Belousov says that each geotectonic cycle is accompanied by the formation of granitic intrusions whose volume is very big but cannot be calculated. Granite has a higher content of radioactive elements than any other rock. The radium content in it is three times as great as in basalt and twice as great as in the most radioactive sedimentary rocks. That is why the formation of granitic intrusions is accompanied by a change in the distribution of radioelements in the Earth: the upper layers of the Earth's crust are enriched with these elements and the deeper layers correspondingly impoverished. But inasmuch as the intrusive process cannot be reversed, the migration of radioactive elements from the Earth's interior to its surface is likewise irreversible. In each tectonic cycle granitic intrusions form in the course of a certain period of the mountain-making epoch. The spasmodic way granite forms in time and space is due to the irregularity of the centrifugal migration of radioelements and of the corresponding thermal conditions in the Earth. The Earth's temperature grows with depth from the surface to the lower boundary of diffusion of radioactive elements, where it reaches its maximum. The centrifugal migration of radioactive elements cools the inner layers of the Earth, of which the most probable consequence is th[...] he volume of matter grows smaller, i. e., contracts.

[...]smodic migration of radioelements is evidently

what causes irregular compressions of the Earth's crust in time and space. But the concentration of these elements primarily under the axial part of a geosyncline starts a fresh inflow of heat generating matter and creates a focus of intensive heating. At some stage or other this must lead to an expansion of matter and a rise of the Earth's crust directly over the area where thermal radiation is greatest. When masses of acid material rise heavier material sinks and this causes compensation downwarps accompanied by the injection of basic intrusions to form in the Earth's crust. Belousov thus recognizes that there are vertical ascending and descending movements of the Earth's crust, the former being accompanied by mountain making. He rejects the possibility of tangential movements.

It still remains to be elucidated how much the abyssal zone below the 70 kilometre suprazone influences tectogenic processes. Another difficulty is that we know very little of the state of matter in the Earth. For example, it is obvious that heating must be the cause of expansion and cooling of compression. But if only the 70 kilometre surface zone expands and compresses the temperature changes cannot ensure the observed amplitude of crustal movements if the process is limited to simple thermal expansion and compression of matter. Changes we know nothing about evidently take place in the aggregate state of matter. Without a knowledge of the physical and chemical properties of abyssal matter it is impossible to make any quantitative computations and this, in its turn, makes it impossible to formulate more or less reliable geotectonic hypotheses.

The time is now ripe to revise, from the standpoint of the latest achievements in all branches of knowledge, all the ideas underlying geotectonic hypotheses. This alone will make it possible to create a scientific and fully substantiated geotectonic theory.

GEOLOGICAL MAPS AND SECTIONS

Geological Maps. These maps are one of the major results of field work. They show the geological structure of various areas of the Earth's surface and of the Earth as a whole. A

geological map brings out the distribution on the Earth's surface of rock layers of different age petrographic composition and mineral content the distribution of underground waters and so on

A basic geological or stratigraphic map shows the distribution of rock layers of different age In addition there are lithologic maps showing the occurrence of various rocks tectonic maps giving the structure of the Earth's crust geomorphologic maps outlining the distribution of various elements of the Earth's surface relief in connection with the geological structure of a given area and the history of the relief's transformation hydrogeological maps showing the distribution of underground waters their quality depth and so forth and mineral maps giving the occurrence quality and other features of minerals

A geological map is compiled on the basis of available topographical data A map showing the relief with contour lines is the most convenient The details and accuracy depend on the scale which is chosen in conformity with the scale of the geological survey

The usual scales for a geological map are 1) areal—from 1 7 500 000 to 1 500 000 2) detailed—from 1 200 000 to 1 50 000 3) special—larger scale

A geological map contains a table of conventional signs (legend) which lists and explains the symbols in it

A colour scale to designate the age of rocks proposed by A Karpinsky was adopted by the 1881 International Geological Congress It gives the following colours for the different stratum systems

Q	Quaternary—light grey or light green
N	Neogene—light yellow
Pg	Paleogene—orange
Cr	Cretaceous—green
J	Jurassic—blue
T	Triassic—light violet
P	Permian—brick red
C	Carboniferous—grey
D	Devonian—brown
S	Silurian—grey green
O	Ordovician—green brown
Cm	Cambrian—violet

A stratigraphical age index is also given in the colour field of a geological map

Magmatic and metamorphic rocks irrespective of their age are also designated by definite colours These are red for acid rocks green for basic rocks and pink for metamorphic rocks

The petrographic composition of rocks is usually depicted with hachures

There is a definite order for the legend in a map The age symbols are given top to bottom or left to right from young to old These are followed by symbols designating magmatic and metamorphic rocks and by the symbols for petrographic varieties of rocks Then follows the explanation of all the signs on the map (elements of the occurrence of strata lines of tectonic disturbances outcrops boreholes and so on)

Certain conventions are permitted in a geological map First and foremost, this concerns Quaternary rocks a thin mantle of which covers almost the entire surface of the Earth and conceals the underlying beds In consequence of this it is the general practice to omit the Quaternary deposits and show the deposits lying directly under them They are only left for areas where they are very thick and no reliable data is available concerning the rocks beneath them (the Caspian region for example) or for areas where intensive sedimentation is proceeding river valleys for instance

To understand a geological map one must be able to picture how the various layers in it harmonise with the relief of the given area

If the strata lie horizontally the colour of the main area shown in the map will be that of the layer closest to the surface strips of older rocks will appear only along valleys and spots indicating younger rocks will be shown in watersheds

The boundaries of the strata will run parallel to the contour of the relief

If the strata are bedded vertically the strips on the map will run along the strike Their width will correspond to the thickness of the strata

If the strata are bedded at an angle the strips on the map

will replace each other in the direction of the dip to indicate the change from older to younger formations (Fig. 113)

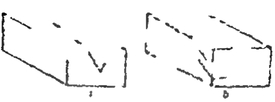

Fig. 113. Block diagrams of horizontal (a) and gently dipping (b) layers

The relation between the boundaries of the strata and the contours depends on the gradient of the area and the dip angle of the strata

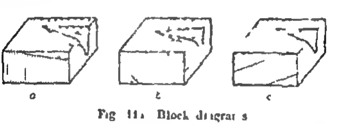

Fig. 114. Block diagrams

—strata incl[illegible] of gu[illegible] gle) [illegible] strat[illegible] gully [illegible] angle) [illegible] strata and the [illegible] gully [illegible] directions

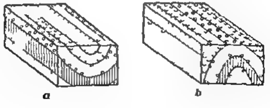

Fig. 115. Block diagrams
a—synclinal fold b—anticlinal fold

If the strata are inclined in the direction of the area gradient (but at a smaller angle than the latter) or if they dip in different directions, the relief contours and the boundaries of the strata will be traced in one and the same direction (Fig 114a, c) If the strata are inclined at a greater angle than the surface relief the relief contours and the boundaries of the strata will be curved in opposite directions (Fig 114b)

On a map folds are represented by stripes repeated symmetrically in relation to the central odd stripe designating the layer in the centre of the fold The difference between syn

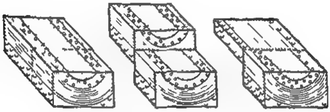

Fig 116 Block diagram of a fault in a syncline
a—syncline before the appearance of a fault b—fault c—abraded fault elevation

clinal and anticlinal folds is in the arrangement of the layers In a syncline the central odd stripe represents the youngest layer (Fig 115a) in an anticline on the contrary it represents the oldest (Fig 115b)

When reading a map showing dislocations with a break in continuity, account must be taken of the strike and dip of the strata and also of the surface gradient (Fig 116)

If the strata are bedded unconformably their boundaries on a map will intersect and one series will give the impression of cutting off another (Fig 117)

On a geological map the width of a stripe representing one and the same layer frequently varies greatly Usually this is due not to the changes in the true thickness of the

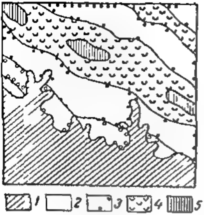

Fig. 117. Unconformably bedded strata
1—Paleogene; 2—Upper Carboniferous; 3—Middle Carboniferous; 4—Lower Carboniferous; 5—Upper Devonian

layer which is nearly always constant but to the surface relief and to the dip of the layer. A stripe representing a definite layer on a map will therefore give the apparent and not true width of the layer. In a gradient with uniform true thicknesses, the apparent thickness of a gently sloping layer will be greater than that of a steeply dipping layer. Conversely, if the dip angle is uniform the apparent thickness will be greater where the dip angle decreases (Fig. 118).

Information about the stratigraphic section of a studied area, i.e., the petrographic composition of the layers, the geological sequence, the thickness and age, is given in a geological or stratigraphic column (Fig. 119).

Geological Section. To give a clearer idea of the way layers are bedded, geological maps are usually accompanied by *geological sections* (*Fig. 120*).

The general principles underlying these sections are:

1. A line whose ends are designated with letters or figures, for example I—I or A—A, is drawn on a geological map in a chosen direction.

2. A scale is selected for the section: the scale of length is usually the same as the scale of the map, while the scale of height may be increased if the strata are thin.

3. The topographic section is constructed on a separate sheet of paper in accordance with the elevation marks along a selected line; it must be at once oriented in relation to *the cardinal points with*

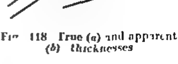

Fig. 118. True (*a*) and apparent (*b*) thicknesses

letter designations at the ends (for example, N—E or S—W)

4 Geological data are written on the topographic profile, the boundaries between the various stratigraphic subdivisions are marked (Fig 121b)

Geological age: System	Epoch	Index	Geological column	Thickness in metres	Brief description of rocks
Quaternary		Q		5 5	Quartz sand yellow brown inequigranular coarse sand predominating
Cretaceous	Lower	C_1		7 8	Grey clay sandy clay on top fine clay below
				25 3	Fine yellow grey sand in lower part passes into semi gravel sand Coarse gravel at the base
Carboniferous	Middle	C_2		10 0	White compact limestone
				5 5	Yellow dolomite with rare fine partings of greenish clay
				2 5	Yellow and grey marl
				2 8	Thin pink grey slate clay
				4 8	Grey compact marl
				20 25	Quartzy sandstone light yellow compact medium grained A layer of semi gravels sandstone with a pebble at the base
				9 5	Fine grained sandstone grey compact
				5 8	Dark grey clay shale

Fig 119 Stratigraphic column

5 The structure is determined by comparing the outcrops of various strata If the bedding is folded the layers in the centre of the folds are traced first The other layers are drawn after that has been done If data is available on elements of the bed position and thickness of the strata the profile

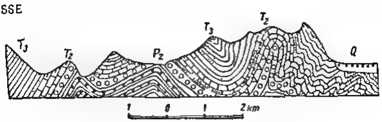

Fig 120 Schematic geological section

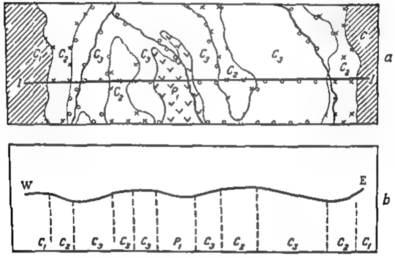

Fig 121 Construction of a schematic geological section

is constructed schematically. In the latter case the strata incline is chosen so that the true thickness of each layer is constant throughout the entire section (Fig. 121 c).

6. A colour or hachure is selected for each profile and is indicated in the legend.

7. The section must be signed.

An ability to read geological maps and sections helps to form a clear picture of the geological structure of a given area, of the types of rocks occuring in that area and also of its geological history.

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